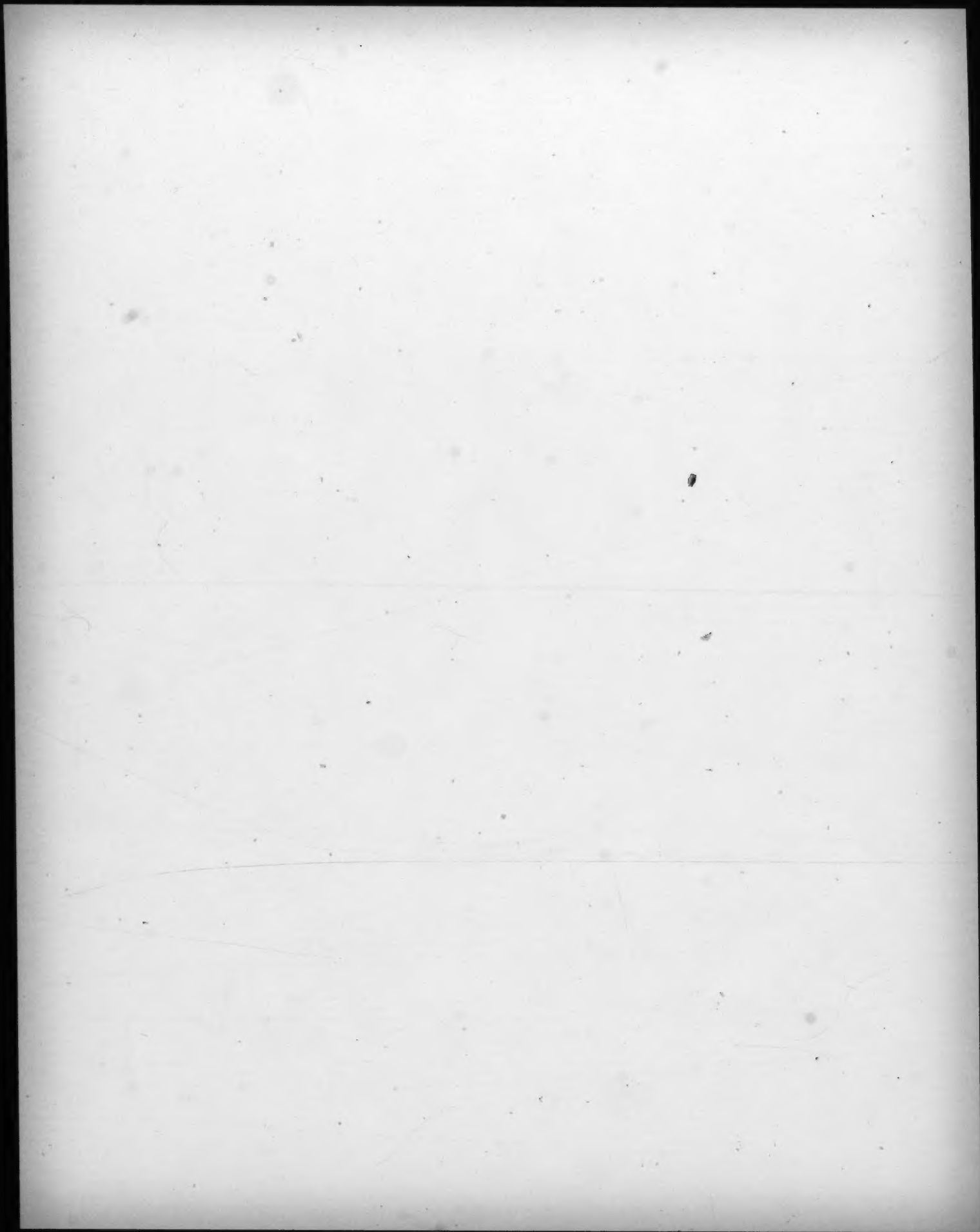


In compliance with the
Canadian Privacy Legislation
some supporting forms
may have been removed from
this dissertation.

While these forms may be included
in the document page count,
their removal does not represent
any loss of content from the dissertation.



University of Alberta

**The Effects of Grazing by Large Herbivores on Carbon and Nitrogen Dynamics in
Montane Grasslands of Jasper National Park**

by

Megan Elizabeth Watters



A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of Master of Science

in

Environmental Biology and Ecology

Department of Biological Sciences

Edmonton, Alberta

Fall 2003



National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisisitons et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

ISBN: 0-612-87910-0

Our file Notre référence

ISBN: 0-612-87910-0

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

Canada

University of Alberta

Library Release Form

Name of Author: Megan Elizabeth Watters

Title of Thesis: The Effects of Grazing by Large Herbivores on Carbon and Nitrogen Dynamics in Montane Grasslands of Jasper National Park

Degree: Master of Science

Year this Degree Granted: 2003

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Submitted: June 26, 2003

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Effects of Grazing by Large Herbivores on Carbon and Nitrogen Dynamics in Montane Grasslands of Jasper National Park submitted by Megan Elizabeth Watters in partial fulfillment of the requirements for the degree of Master of Science in Environmental Biology and Ecology.

/Dr. Suzanne Bayley/ 

Date Thesis Approved: June 26, 2013

Abstract

To quantify the effects of grazing on vegetation and soils in the montane grasslands of Jasper National Park, I conducted a series of vegetation and soil surveys at 9 grassland sites in 2001-2002. Since 1946, grassland vegetation cover has not improved as much as expected given reduced ungulate numbers and improved precipitation, possibly due to grassland succession to forest. Although plant cover, carbon and nitrogen inputs, and species composition were affected by past grazing regimes, belowground variables including root biomass, microbial biomass and activity, soil N and soil moisture, did not differ from undefoliated plots after 2 year of seasonal clipping or by past grazing. Soil type, however, had a strong effect on belowground variables, with lower root biomass, microbial biomass, soil moisture and mineral N on sandy soils than loamy soils. I suggest that future research focus on the effects of grassland management and exploring various soil nutrient indicators.

Acknowledgements

My research would not have been possible without funding or logistical support from: Jasper National Park, Rocky Mountain Elk Foundation, National Science and Engineering Research Council (NSERC), Biodiversity Grant (U of A), Department of Biological Sciences (U of A), Mary Louise Imrie Graduate Student Award (U of A), and Mountain Equipment Coop.

I would like to thank all the Park personnel in Jasper, especially: George Mercer, for helping haul cages and reviewing my manuscripts; Peter Achuff, for providing his expert opinion; Alan Westhaver, for his invaluable support in erecting Richardson enclosure; Wes Bradford, for his knowledge of wildlife in the park and the loan of a bear banger; Kim Forester, for spending many hours helping me in the library; Leigh Pitoulis, Deb Joly and all the Palisades staff, for providing moral support and being my family away from home; Sherrill Merropoulis, for providing me with many enthusiastic volunteers; Vicki Wallace, for becoming a good friend, and; the Fire Crew, for rescuing my samples from burning in the drying oven, bending rebar, and putting up with me "drying weed" all summer.

My research would have been much more difficult without all the enthusiastic volunteers I was privileged to work with, who came from far and wide to help. These special folks were: Helena Svedova, Kristen Kolar, Janna Howell, Tracy McKay, Natalia Riley, Carol Peters, Marci Johnson, Mike Gregor, Tessa Hagendoorn, Cassie Corbin, Karlie Wilson, Darren Villeneuve, Iain Reynolds, Nicole Manhard, Evelyn Day, and Tammy & Mat McLash.

I also want to thank my supervisor Dr. Evie Merrill for encouraging me to do my best work and showing me I can achieve what I thought was out of reach. She has taught me much about biology and life, and has been a good friend. My lab mates also provided both academic and moral support, especially Leslie McInenly, Jacqui Frair, and Doris Simader. I am particularly grateful to Doris for helping edit my thesis.

Finally, I am grateful for the never-ending support of my parents, Brian and Angela Watters. They always listened and sympathised with my latest graduate school crisis, and I could not have done it without them.

Table of Contents	Page
Abstract.....	
Acknowledgements.....	
Table of Contents.....	
List of Tables.....	
List of Figures.....	
Chapter 1. Plant-herbivore Dynamics in National Park.....	1
Research Objectives.....	6
Reference List.....	8
Chapter 2. Past and Present Factors Affecting the Montane Grasslands of Jasper National Park, Alberta.....	12
Introduction.....	12
Methods.....	16
<i>Field Methods</i>	16
<i>Data Analyses</i>	18
Results.....	20
<i>Effects of Grazing in 2002</i>	20
<i>Long-term Trends in Grazed Grassland</i>	23
<i>Long-term Effects of Grazing</i>	26
Discussion.....	26
Conclusions.....	33
Management Suggestions.....	33
Reference List.....	36

Chapter 3. The Effect of Herbivory and Soil Texture on Carbon and Nitrogen Dynamics in Montane Grasslands of Jasper National Park, Alberta.....	38
Introduction.....	38
Methods.....	44
<i>Defoliation Treatments</i>	44
<i>Aboveground Biomass</i>	45
<i>Root Biomass</i>	47
<i>Microbial Biomass Carbon and Nitrogen</i>	47
<i>Soil Mineral N and net N Mineralization</i>	48
<i>Vegetation Utilization Estimates</i>	50
<i>Statistical Analyses</i>	51
Results.....	52
Discussion.....	61
Conclusions.....	69
Future Direction.....	70
Reference List.....	72
Chapter 4. Moving Towards Ecological Integrity.....	78
Reference List.....	84
Appendix A. Site Descriptions, Maps, and Photographs.....	85
Exclosure List.....	85
Cottonwood Point.....	87
Cottonwood Slough.....	89

Devona Hill.....	91
Edna.....	93
Henry House.....	95
Moberly.....	97
Richardson.....	99
Warden's Office.....	101
Windy Point.....	103

Appendix B. Complete Vegetation Data

Species List.....	105
Cottonwood Point.....	107
<i>Fenced Canopy Cover (2002)</i>	107
<i>Grazed Canopy Cover (2002)</i>	108
<i>Fenced Canopy Cover (1995-2002)</i>	109
<i>Grazed Canopy Cover (1995-2002)</i>	110
<i>Fenced Range Condition (2002)</i>	111
<i>Grazed Range Condition (2002)</i>	112
Cottonwood Slough.....	113
<i>Fenced Canopy Cover (2002)</i>	113
<i>Grazed Canopy Cover (2002)</i>	114
<i>Fenced Canopy Cover (1995-2002)</i>	115
<i>Grazed Canopy Cover (1995-2002)</i>	116
<i>Fenced Range Condition (2002)</i>	117
<i>Grazed Range Condition (2002)</i>	118

Devona Hill.....	119
<i>Fenced Canopy Cover (2002)</i>	119
<i>Grazed Canopy Cover (2002)</i>	120
<i>Fenced Canopy Cover (1995-2002)</i>	121
<i>Grazed Canopy Cover (1995-2002)</i>	122
<i>Fenced Range Condition (2002)</i>	123
<i>Grazed Range Condition (2002)</i>	124
Edna.....	125
<i>Fenced Canopy Cover (2002)</i>	125
<i>Grazed Canopy Cover (2002)</i>	126
<i>Fenced Canopy Cover (1995-2002)</i>	127
<i>Grazed Canopy Cover (1995-2002)</i>	128
<i>Fenced Range Condition (2002)</i>	129
<i>Grazed Range Condition (2002)</i>	130
Henry House.....	131
<i>Fenced Canopy Cover (2002)</i>	131
<i>Grazed Canopy Cover (2002)</i>	132
<i>Fenced Canopy Cover (1968-2002)</i>	133
<i>Grazed Canopy Cover (1968-2002)</i>	134
<i>Fenced Range Condition (2002)</i>	135
<i>Grazed Range Condition (2002)</i>	136
Moberly.....	137
<i>Fenced Canopy Cover (2002)</i>	137

<i>Grazed Canopy Cover (2002)</i>	138
<i>Fenced Canopy Cover (1968-2002)</i>	139
<i>Grazed Canopy Cover (1968-2002)</i>	140
<i>Fenced Range Condition (2002)</i>	141
<i>Grazed Range Condition (2002)</i>	142
Richardson.....	143
<i>Fenced Canopy Cover (2002)</i>	143
<i>Grazed Canopy Cover (2002)</i>	144
<i>Fenced Range Condition (2002)</i>	145
<i>Grazed Range Condition (2002)</i>	146
Warden's Office.....	147
<i>Fenced Canopy Cover (2002)</i>	147
<i>Grazed Canopy Cover (2002)</i>	148
<i>Fenced Canopy Cover (1995-2002)</i>	149
<i>Grazed Canopy Cover (1995-2002)</i>	150
<i>Fenced Range Condition (2002)</i>	151
<i>Grazed Range Condition (2002)</i>	152
Windy Point.....	153
<i>Fenced Canopy Cover (2002)</i>	153
<i>Grazed Canopy Cover (2002)</i>	154
<i>Fenced Canopy Cover (1995-2002)</i>	155
<i>Grazed Canopy Cover (1995-2002)</i>	156
<i>Fenced Range Condition (2002)</i>	157

<i>Grazed Range Condition (2002)</i>	158
Appendix C. Additional Chapter 2 Data and Methods	159
Soil and Vegetation Sampling Dates.....	159
Jasper National Park Climatic Data.....	160
Conversion of Relative % Frequency Data to Canopy Cover...	161
<i>Methods</i>	161
<i>Graphs</i>	162
<i>Data Values</i>	163
Comparison of Bantū and Jasper Climate.....	170
Appendix D. Additional Chapter 3 Data and Methods	171
Soil and Vegetation Sampling Dates.....	171
Comparison of Exclosure Dates on Soil Characteristics.....	173

List of Tables**Page**

Table 2.1. Vegetation and soil characteristics of 9 study sites in Jasper National Park.....	17
Table 2.2. Percent canopy cover of major species and vegetation classes across all 8 sites and by soil type.....	21
Table 2.3. Long-term vegetation trends at 5 grassland sites in Jasper National Park.....	25
Table 3.1. Pellet group densities at 9 grassland sites in Jasper National Park, Alberta.....	52
Table 3.2. Mean and standard deviation of total standing aboveground biomass, root biomass and length, root/aboveground biomass ratio in plots subject to seasonal clipping treatments, sampled in spring and fall 2001.....	56
Table 3.3. Mean and standard deviation of microbial biomass C and N, microbial C/N ratio, N mineralization, mineral N, and soil moisture in plots subject to seasonal clipping treatments, sampled in spring and fall 2001.....	57
Table 3.4. Mean and standard deviation of total standing aboveground biomass, root biomass and length, root/aboveground biomass ratio in plots subject to seasonal clipping treatments, sampled in spring and fall 2002.....	58
Table 3.5. Mean and standard deviation of microbial biomass C and N, microbial C/N ratio, N mineralization, mineral N, and soil moisture in plots subject to seasonal clipping treatments, sampled in spring and fall 2002.....	59
Table 3.6. Mean and standard deviation of total standing aboveground biomass, root biomass and length, root/aboveground biomass in sandy and loamy grasslands sampled in spring and fall 2001 and 2002.....	62
Table 3.7. Mean and standard deviation of microbial biomass C and N, microbial C/N ratio, N mineralization, mineral N, soil moisture, and leached N in sandy and loamy grasslands sampled in spring and fall 2001 and 2002.	63

List of Figures

Page

Fig 2.1. . A) Effect of ungulate use intensity on species richness, and B) effect of ungulate use intensity on difference in species richness between fenced and grazed plots, Jasper National Park, Alberta.....	22
Fig 2.2. Regression of elk pellet group density and distance from the centre of Jasper town, Alberta.....	24
Fig 2.3. Winter and summer pellet group densities at 9 grassland sites in Jasper National Park, Alberta.....	24
Fig 2.4. The difference in % canopy cover of vegetative classes and bare soil between fenced and grazed plots at: A) sandy sites, and B) loamy sites for 1995 and 2002 in Jasper National Park, Alberta.....	27
Fig 2.5. Elk population trends in Jasper National Park, Alberta.....	28
Fig 3.1. Relationship between microbial biomass C and pellet group density at 9 sites in Jasper National Park, Alberta.....	54
Fig 3.2. Relationship between microbial biomass and standing above- ground biomass at 9 sites in Jasper National Park, Alberta.....	54
Fig 3.3. Relationship between microbial biomass and root biomass at 9 sites in Jasper National Park, Alberta.....	55
Fig 3.4. Relationship between N mineralization and standing above- ground biomass at 9 sites in Jasper National Park, Alberta.....	55

CHAPTER 1

Plant-Herbivore Dynamics in National Parks

National Parks provide a unique opportunity to study plant-herbivore dynamics under "natural" conditions because they provide baselines (Arcess and Sinclair 1997). For example, in 1968, a natural regulation policy was adopted in Yellowstone National Park where ungulate populations were not actively managed by Park officials (Coughenour and Singer 1991, Singer *et al.* 1998, Huff and Varley 1999), with the expectation that they would reach an equilibrium within the Park and exhibit stable population dynamics in spite of natural environmental variability (Coughenour and Singer 1991). Yet, there is heated debate over the natural regulation hypothesis and the long-term sustainability of Yellowstone grasslands (Huff and Varley 1999) and willow/aspen communities (Chadde and Kay 1991, Singer *et al.* 1998). At the same time as natural regulation was adopted in Yellowstone, Rocky Mountain National Park also adopted a policy where elk (*Cervus elaphus*) populations were no longer controlled within the Park's boundaries (Singer 2002). By 1993, however, high elk population numbers and declining vegetation cover led to criticism of the Park elk policy (Hess 1993). The U.S. National Park Service policy states that "natural processes should be relied upon to the largest extent possible to manage wildlife populations within National Parks, but that high populations of animals may be managed, if those over-concentrations are due to human activities (NPS 2001)".

Canadian National Parks, including Jasper National Park, did not adopt a natural regulation policy until the 1970's (*pers. comm.* K. van Tighem), and Jasper has a history of human intervention, including elk culling and predator poisoning programs. Carbyn

(1973) suggested that human intervention may be destabilizing elk populations and in fact increasing elk numbers in Jasper, resulting in not only unhealthy elk, but heavily grazed grasslands and even in the decline of caribou and sheep. Recent Park policy on the regulation of natural systems from the Parks Canada's Guiding Principles and Operating Policies (1994) can be summarized in the following:

"National park ecosystems will be managed with minimal interference to natural processes. However, active management may be allowed when the structure or function of an ecosystem has been seriously altered and manipulation is the only possible alternative available to restore ecological integrity (Sec 3.2.3 p 34)."

Jasper's grasslands have a long history of both native and introduced herbivores. Although native people were said to have had horses (Anderson and Reeves 1975), the first large-scale introduction of horses to Jasper's grasslands occurred with European arrival, during a period of wide fluctuations in native ungulates. European influence on grasslands in the Jasper National Park area began in 1810, when David Thompson, mapmaker and surveyor, made the first recorded visit to the Athabasca Valley (Pfeiffer 1948, Smith 1991). Thompson and other traders brought horses to the montane grasslands, the first of many explorers, settlers, outfitters and Park's personnel to graze livestock on Jasper's montane grasslands. This practice continued until the 1960's (JNP 2000). Between 1934 and 1947, an average 176 horses and 20 cattle were officially grazed in the Athabasca Valley, and these estimates do not include the 85 government horses that used ranges in winter, and an additional ~25 wild horses running in the valley (Pfeiffer 1948). Heavy livestock use and increasing native ungulate populations in the 1940's contributed to concerns of overgrazing in the 1940's and 1950's (Cowan 1946).

Historically, a number of ungulate species have occupied Jasper (Anderson and Reeves 1975). Wood bison (*Bison bison athabasca*) were exterminated in Jasper between 1825 and 1850. Mule deer (*Odocoileus hemionus hemionus*), moose (*Alces alces andersoni*), and bighorn sheep (*Ovis canadensis canadensis*) are common ungulates found in Jasper both historically and today. Moose underwent a steady population decline in the latter half of the 19th century and the early 1900's (Anderson and Reeves 1975), but have never been well studied. Mule deer compete for similar habitat as elk, and also suffered a drastic decline due to hunting pressures, disease, and severe winters around the turn of the century (Anderson and Reeves 1975). Range expansion by white tail deer (*Odocoileus virginianus*) is also thought to have reduced mule deer numbers (pers. comm. G. Mercer, JNP). Early explorers commented on the abundance of sheep in the Jasper area and at times in the mid-19th century, remained the only ungulate in the Athabasca Valley (Anderson and Reeves 1975). Bighorn sheep also compete with elk for habitat, although sheep tend to occupy more rugged terrain than elk. Elk (*Cervus elephas*) were a historic component of the eastern slopes of the Rocky Mountains (JNP 2000), although the extent of their numbers is unclear (Wolff 1975, Kay *et al.* 1994). Carbyn (1973) reported that there was no evidence that elk were abundant at earlier times, given the small role of elk in the fur trade. In the northeastern section of Jasper, near Pocahantas, antler fragments, classified as elk, have been dated at 1900 B.C.E. (Dekker *et al.* 1993).

Elk, moose, and mule deer populations all suffered a drastic reduction in the mid 19th century (Anderson and Reeves 1975). Jasper elk were extirpated around 1894 as a result of a series of harsh winters and over-hunting (Wolff 1975). The near-total

eradication of the elk population, along with poisoning by Hudson's Bay post-masters in 1859, resulted in the disappearance of wolves from Jasper by the end of the 1800's (Dekker *et al.* 1993). In 1920, 88 elk were relocated from Yellowstone to Jasper, and by 1926, the elk population had increased to between 1000 and 2000 individuals, an increase of 10 -25% per year (Dekker *et al.* 1993). Jasper elk continued to thrive, such that a population of 2500 was reached in 1945 (Bradford 1999). As ungulate populations rebounded, wolves returned to the Park and increased to such a level to cause concern that wolves would reduce the ungulate populations (Dekker *et al.* 1993). Between 1940 and 1959, Park officials reduced predators, including wolves, in the Athabasca Valley in an attempt to control rabies (JNP 2000), resulting in an increase of elk to 2500 individuals.

In response to concern over range condition in this period (Banfield 1952), elk were culled from 1942-1970 (Bradford 1999), with 1546 elk harvested between 1942 and 1955 alone (Flook 1955). Since the 1970's wolf populations increased again to an estimated 80-100 animals park-wide (Dekker *et al.* 1993). In aerial surveys in 1971 and 1973, Stelfox and Bindernagel (1978) recorded an average of 2000-2500 elk each year in the entire Park. By 1975, elk range was reduced to core areas of primary habitat in the Athabasca Valley, and elk populations remained near 1000 from 1980-1992, while wolf populations stabilized at 40-50 animals (Dekker *et al.* 1993). Increasing wolf populations in the early 1990's may have driven elk towards the townsite, which provided a predator refuge, as well as an easy food source.

Between 1995 and 1998, 250 habituated elk were year-round residents in high-use areas (HUA's), including the Jasper townsite, Jasper Park Lodge, and Whistler's

campground, and were commonly seen in these areas during the summer (*pers. comm.* W. Bradford, JNP). In contrast, during the mid 1980's, only about 50 elk were year-round residents in the same area, and were not commonly seen in HUA's during the summer. By the mid- to late-1990's, elk were having a severe impact on grassland vegetation close to HUA's, while not having a major impact on range vegetation in other parts of the Park (*pers. comm.* W. Bradford, JNP). This concern prompted the translocation of 220 elk, representing ~15% of the Parks' elk population, in 1999 and 2000 from the townsite area (JNP 2000).

Increasing concern about range deterioration over the years resulted in several studies of ungulate herbivory in Jasper on aboveground production and species composition (Cowan 1946, Banfield 1952, Stringer 1968, Trottier 1979, Tannas 1997). These studies show a general reduction in vegetative cover with grazing and increases in species including junegrass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.), pasture sage (*Artemisia frigida* (Willd.)), and pussytoes (*Antennaria* spp.). In contrast, Northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), fescue (*Festuca saximontana* Rydb.), and leguminous forbs decreased with herbivory (Trottier 1979, Tannas 1997). Only two studies have addressed soil energy and nutrient properties in Jasper, and did not focus on the effect of grazing (Pfeiffer 1948, Stringer 1968). However, Stringer (1968) reported that grazing tended to reduce soil moisture and increase soil temperature, while not having a strong effect on organic carbon. Because Park managers want to understand the "underlying disfunction (JNP 2000)" and not simply address the symptoms, it is necessary to understand not only the effects of grazing on vegetation, but on the flow of

nutrients through the grassland system (Augustine and Frank 2001), and how ungulates can affect their own forage supply (Botkin 1990).

In 2002, I studied the influence of grazing on plant species composition and soil characteristics of montane grasslands in Jasper National Park at sites that differed in soil texture. To understand the effect of seasonal grazing, I conducted seasonal clipping experiments within 9 exclosures in 2001 and 2002, while also comparing naturally grazed grassland with controls within the exclosure. To examine the effects of defoliation on available C/N measures, I collected data on above- and below-ground plant biomass, microbial biomass amount and activity, total mineral N pools, and plant species composition.

Specific questions addressed included:

- 1) Does plant species composition differ between sandy and loamy grasslands, and is there an interaction between grazing and soil texture?
- 2) What is the intensity and timing of grazing on Jasper's grasslands?
- 3) How does long-term grazing affect plant species composition and species richness?
- 4) How does seasonal long- and short-term defoliation affect both above- and below-ground biomass, and carbon and nitrogen availability?
- 5) Do plant and soil characteristics vary with soil texture, and does soil texture influence the effects of grazing?

Research Objectives

My thesis addresses 2 components. In Chapter 2, I address the effects of long-term herbivore exclusion and soil texture on species composition inside and outside 9

permanent, ungulate-proof exclosures. I used ungulate pellet group counts to measure ungulate utilization at each site. Plant species composition surveys were conducted along 4 marked transects inside and 4 outside each exclosure. To understand range trends over the past 60 years in Jasper, I compared present composition and % cover values with historical data at some sites. In Chapter 3, I address the effects of both long-term herbivore exclusion and short-term defoliation in soil with different textures on C/N dynamics. Vegetation from experimental plots within the exclosure was clipped in the winter only, winter and spring, or year-round (winter, spring, and summer). To look at the effects of seasonal defoliation on C/N measures, I measured above- and below-ground biomass, microbial biomass and activity, and mineral N from each experimental plot and outside the exclosure in naturally grazed areas. In Chapter 4, I summarize my results and put them in the context of other National Parks, and issues surrounding grassland management.

Reference List

- Anderson and Reeves. 1975. Jasper National Park archeological inventory. Jasper National Park.
- Arcese, P., and A.R.E. Sinclair. 1997. The role of protected areas as ecological baselines. *J. Wildl. Manag.* 61(3): 587-602.
- Augustine, D.J., and D.A. Frank. 2001. Effects of migratory grazers on spatial heterogeneity of soil nitrogen properties in a grassland ecosystem. *Ecol.* 82(11): 3149-3162.
- Bailey, A., M.G. Willoughby, and B.D. Irving. 1988. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Research Program. Edmonton, Alberta.
- Banfield, A. W. F. 1952. Range studies, Jasper National Park.
- Biondini, M.E., B.D. Patton, and P.E. Nyren. 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecol. Appl.* 8: 469-479.
- Botkin, D. 1990. *Discordant Harmonies*. Oxford University Press. Oxford. 241 pp.
- Bradford, W. 1999. Report on the 1999 aerial census of elk along the Athabasca and Miette Valleys of Jasper National Park.
- Cardon, Z.G., A.D. Czaja, J.L. Funk, and P.L. Vitt. 2002. Periodic carbon flushing to roots of *Quercus rubra* saplings affects soil respiration and rhizosphere microbial biomass. *Oecologia*. 133: 215-223.
- Chadde, S.W., and C.E. Kay. 1991. Tall-willow communities on Yellowstone's Northern Range: A test of the "natural regulation" paradigm. *In* The Greater Yellowstone Ecosystem: redefining America's wilderness heritage. Eds. R.B. Keiter and M.S. Boyce. Yale University Press, USA.
- Coughenour, M.B., and F.J. Singer. 1991. The concept of overgrazing and its application to Yellowstone's northern range. *In* The Greater Yellowstone Ecosystem: redefining America's wilderness heritage. Eds. R.B. Keiter and M.S. Boyce. Yale University Press, USA.
- Cowan, I. McT. 1946. General report upon wildlife studies in the Rocky Mountain Parks. Canadian Wildlife Service. Edmonton, Alberta.
- Dekker, D., W. Bradford, and J. Gunson. 1993. Elk and wolves in Jasper National Park, Alberta, from historical times to 1992. A review of the status of wolves. *Wolves in a Changing World*.
- Dormaar, J.F., and W.D. Willms. 1998. Effect of forty-four years of grazing on fescue

- grassland soils. *J. Range Manage.* 51: 122-126.
- Flook, D.R. 1955. An appraisal of the elk situation in the Athabasca Valley of Jasper Park. Canadian Wildlife Service. Edmonton, Alberta. Pp. 9
- Frank, D.A., and R.D. Evans. 1997. Effects of native grazers on grassland N cycling in Yellowstone National Park. *Ecol.* 78: 2238-2248.
- Frank, D.A., and S.J. McNaughton. 1992. The ecology of plants, large mammalian herbivores, and drought in Yellowstone National Park. *Ecol.* 73: 2043-2058.
- Frank, D.A., and S.J. McNaughton. 1993. Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. *Oecologia* 96: 157-161.
- Hassink, J., L.A. Bouwman, K.B. Zwart, J. Bloem, and L. Brussard. 1993. Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils. *Geoderma* 57: 105-128.
- Hess, K. 1993. Rocky Times in Rocky Mountain National Park. University Press of Colorado, Niwot. 167 pp.
- Holland, E.A., and J.K. Detling. 1990. Plant response to herbivory and belowground nitrogen cycling. *Ecol.* 71: 1040-1049.
- Hopkins, W.G. 1999. Introduction to Plant Physiology. John Wiley and Sons, Inc., USA.
- Jasper National Park Warden Service. 2000. Elk Management Plan: Jasper National Park.
- Kay, C. E., B. Patton, and C.A. White. 1994. Assessment of long-term terrestrial ecosystem states and processes in Banff National Park and the central Canadian Rockies. Banff National Park.
- Liu, A., and C. Tang. 1999. Comparative performance of *Lupinus albus* genotypes in response to soil alkalinity. *Australian Journal of Agricultural Research* 50: 1435-1442.
- MacKinnon, A., J. Pojar, and R. Coupe. 1999. Plants of Northern British Columbia. Lone Pine Publishing, Vancouver, British Columbia.
- National Park Service. 2001. Management policies. U.S. Government Printing Office, Washington, D.C.
- McNaughton, S.J. 1983. Serengeti grassland ecology: the role of composite environmental factors and contingency in community organization. *Ecol. Monogr.* 53: 291-320.
- McNaughton, S.J. 1985. Ecology of a grazing ecosystem: the Serengeti. *Ecol. Monogr.*

55: 259-294.

- McNaughton, S.J. 1989. Interactions of plants in the field layer with large herbivores. Symposium of the Zoological Society of London. 61: 15-29.
- Pfeiffer, E.W. 1948. Some factors affecting the winter ranges of Jasper National Park. M.Sc. Thesis, University of British Columbia. Vancouver, British Columbia.
- Rhemtulla, J.M. 1999. Eighty years of change: the montane vegetation of Jasper National Park. M.Sc. Thesis, University of Alberta. Edmonton, Alberta.
- Ricklefs, R.E. 1973. Ecology. Chiron Press. Portland, Oregon.
- Rusch, G.M., and M. Oesterheld. 1997. Relationship between productivity, and species and functional group diversity in grazed and non-grazed Pampas grassland. *Oikos* 78: 519-526.
- Rutherford, P.M. and N.G. Juma. 1992. Influence of texture on habitable pore space and bacterial-protozoan populations in soil. *Biol. Fert. Soils* 12: 221-227.
- Singer, F.J. 2002. In Singer, F.J., and L.C. Ziegenfuss, compilers. 2002. Ecological evaluation of the abundance and effects of elk herbivory in Rocky Mountain National Park, Colorado, 1994-1999. Final report to the National Park Service, Rocky Mountain National Park on Cooperative Agreement No. 1445-0009-94-1074 (USGS) Subagreement 2 between the National Park Service, Biological Resources Discipline, of the U.S. Geological Survey, and Natural Resources Ecology Laboratory, Colorado State University. Open File Report 02-208. 268 pp.
- Singer, F.J., L.C. Zeigenfus, R.G. Cates, and D.T. Barnett. 1998. Elk, multiple factors, and persistence of willows in national parks. *Wildl. Soc. Bull.* 26: 419-428.
- Smith, C. 1991. People, places and events: a history of Jasper National Park. Jasper National Park.
- Stelfox, J. G., and J.A. Bindernagel. 1978. Cariboo behaviour in relation to Human-Elk-Wolf influences: Jasper National Park 1971-1974. Canadian Wildlife Serv. Edmonton, Alberta.
- Stringer, P.W. 1973. An ecological study of grasslands in Banff, Jasper, and Waterton Lakes National Parks. *Can. J. Bot.* 51: 383-411.
- Tande, G.F. 1979. Fire history and vegetation pattern of coniferous forests in Jasper National Park, Alberta. *Can. J. Bot.* 57: 1912-1131.
- Tannas, C. A. 1997. Analysis of range exclosures Jasper National Park. Parks Canada.
- Tracy B.F., and D.A. Frank. 1998. Herbivore influence on soil microbial biomass and nitrogen mineralization in a northern grassland ecosystem: Yellowstone National

Park. *Oecologia* 114: 556-562.

Trottier, G. C. 1979. Analysis of range exclosures, Jasper National Park (1978).
Canadian Wildlife Serv. Edmonton, Alberta.

Wolff, S. 1975. Historical background information for the east highway interpretive unit
plan. Jasper National Park.

CHAPTER 2

Past and Present Factors Affecting the Montane Grasslands of Jasper National Park, Alberta

Introduction

Grasslands have long supported large populations of migratory herbivores, promoting the coevolution of grasses and grazers (McNaughton 1989). Since the arrival of Eurasian people and domestic livestock, grassland-herbivore dynamics have changed (Holechek *et al.* 2001). Because domestic animals are regulated by stocking rates rather than by plant-herbivore dynamics and are usually not migratory, intensive cattle grazing often reduces vegetation cover (Rusch and Oesterheld 1997), thereby reducing litter cover, soil organic matter (Dormaar and Willms 1998) and increasing erosion. In natural populations of herbivores, such as those within National Parks, it is believed that populations undergo regulation in response to food availability and predator density (Coughenour and Singer 1991, Singer *et al.* 1998), and that system feedbacks are important for developing dynamic equilibria between vegetation and herbivores.

In other semi-arid grasslands, it has been shown that the effect of herbivory on grasslands depends on grazing intensity (Holland and Detling 1990), timing (Bailey *et al.* 1988), available moisture, and grazing history (Milchunas and Lauenroth 1993). At high grazing intensities, such as with year-round grazing, production tends to decrease (Holland and Detling 1990, Detling 1998) because plants are unable to recoup before senescence (Holechek *et al.* 2001). Low to moderate grazing intensities, particularly in the winter and/or spring, may increase production (Frank and McNaughton 1992), perhaps because of accelerated regrowth rates (McNaughton 1983), improved water use efficiency (Wraith *et al.* 1987), greater nutrient cycling and availability due to increased

soil moisture and temperature, resulting from a loss in litter accumulation (Frank and McNaughton 1993). This "intermediate disturbance hypothesis" may apply in relatively mesic grassland systems, with a long history of grazing, but in semi-arid sites, such as Jasper, grassland production, as well as species richness, may decrease linearly with increasing grazing intensity (Milchunas and Lauenroth 1993). Thus, the effect of grazing in Jasper will depend on the intensity and timing of defoliation, with year-round vegetation removal likely reducing aboveground productivity the most. For this reason, changes in migratory behavior of native herbivores relative to range condition are of particular interest to managers in Jasper National Park.

Range condition has traditionally been defined by comparing current plant species with those in a "climax community" (Wroe *et al.* 1988). The climax model implies that changes in vegetation species are predictable and will revert back to a pre-disturbance community once the disturbance, such as grazing, is removed (Willoughby 1997). Exclosures help researchers gain information on what species comprise a climax community and provide benchmarks against which grazed range condition can be compared (Willoughby 1997). However, research has found that despite removal of herbivory, invasive species may remain a major component of the plant community (Willoughby 1997) and that vegetation dynamics may follow a "state and threshold model" (Laycock 1991). In this model, a plant community invaded by non-native species is unlikely to return to one dominated by native species, thus reducing range condition.

Jasper National Park has one of the longest-running vegetation monitoring programs in North America (JNP Warden Service). In response to apparent deterioration of ungulate winter ranges with increasing elk populations, the National Park Service

established exclosures in 1942 at 6 sites throughout the Athabasca Valley, chosen on the basis of winter-use by ungulates, and were considered representative of winter ranges (Pfeiffer 1948, Banfield 1952, Flook 1955). Cowan (1946) found that in 1946, vegetation cover was low, while bare ground cover ranged between 54.3 – 80.0%, and that most of the Athabasca ranges were in “deplorable condition... in large measure... due to overstocking with elk [2500 individuals] but in two areas horses were the most important single agent contributing to overgrazing.” Despite elk reductions in 1946-1947 and higher precipitation, Banfield (1952) reported that of the 9 ranges sampled in 1952, only 2 sites had increased vegetation cover, while vegetation at the other sites exhibited a 3-20% decline in cover. Banfield (1952) warned that “this [was] the last moment to save the situation”, and recommended both the immediate cessation of all winter grazing of horses in the Athabasca Valley north of Jasper townsite and Old Fort Point, and the culling of 200 elk during the winter of 1952-1953. Based on evidence of extensive terracing and erosion, Flook (1955) reported that winter ranges were still in apparently poor condition in 1955, despite the harvest of 275 elk in 1952-1955. As a result, 200 elk were killed in 1956, and horse grazing and predator control were ceased in the early 1960's (Dekker *et al.* 1993). In 3 exclosures from 1956, Stringer (1969) found that in 1968, grazing reduced graminoid cover and standing biomass, especially at the more xeric sites of Moberly and Henry House and that there was a noticeably thicker Ah horizon in Devona flats exclosure, while soil was not strongly affected by fencing at Moberly and Henry House (Stringer 1969).

By the early 1970's, elk populations had also decreased to ~500 individuals, due to culling efforts and harsh winters (JNP 2000). By July 1978, Trottier (1979), based on

surveys at all remaining exclosures, concluded that higher precipitation and reduced grazing intensity were responsible for increased graminoid cover and improved range condition since 1957. In particular he found that fencing promoted the relative dominance of *Agropyron* spp. over *Koeleria macrantha*, rather than the addition or loss of species (Trottier 1979). With elk numbers reaching ~1500 in the 1990's, Tannas (1997) found that since 1978, graminoid cover had increased or remained constant at most sites, despite elk numbers reaching ~1500 in 1990's, but that overall vegetation cover was greater with fencing.

The purpose of my research was to add to the existing long-term monitoring and to meet the following objectives:

- 1) Determine whether vegetation cover and species richness differed inside and outside the ungulate-proof exclosures in 2002.
- 2) To test whether grasslands close to town receive greater use than those further away, and to determine if summer use equals winter use (year-round use).
- 3) Assess changes across time in grazed vegetation cover outside exclosures.

This information will help managers within Parks Canada to direct future management of grasslands in the face of changing ungulate population numbers and grassland area. In July 2001, I established a new exclosure, Richardson, in a *Stipa richardsonii* meadow along Snaring Road to diversify the types of grassland and soil type represented by the exclosures. In July 2002, I conducted intensive vegetation surveys at 9 of the 12 exclosure sites, excluding Disaster Point, Sulfur Ridge, and Devona Flats. Devona Flats was intentionally excluded because of wolf willow (*Eleagnus commutata*)

encroachment, while Disaster Point and Sulfur Ridge were excluded because they were primarily sheep habitat.

I hypothesized that ungulate grazing on the low elevation grasslands of Jasper National Park would reduce overall plant standing biomass, plant species diversity, and promote invasion of non-native species, while grass species like *Agropyron spp.* and *Stipa richardsonii* would be higher in fenced grassland communities. Further, because elk and sheep have generally decreased since 1950s (Trottier 1979, JNP 2000), I hypothesized that there would be higher vegetative cover outside the exclosures at these sites in 2002 than in the 1940s and 1950s. Lastly, I hypothesised that elk use would be greater closer to the townsite, and that most grasslands would receive at least some year-round use.

Methods

Field Methods

In July 2002, I conducted vegetation surveys at 9 of the 12 montane grassland sites established as part of a long-term monitoring program to document plant composition and abundance (Table 2.1, Appendix A). Each site had 4 permanently marked transects (8 m long, 2 m apart) inside and outside an exclosure. I used 3 methods of data collection at each site. The first method was the Canopy Coverage Method of Vegetation Analysis (Wroe *et al.* 1988; Robertson and Adams 1990), and was used because it is one of the most commonly used methods of vegetation analysis and thus comparable to both studies conducted in 1995 by Tannas (1997) and studies in other grasslands. I collected data from a total of 32 Daubenmire frames (0.1 m^2) within each exclosure and another 32 frames outside. In each frame, I estimated the percent canopy

cover of total standing material, green and dead, for each species, by cover class. Moss, lichen, cryptogamic soil crust, and *Nostoc* spp. algae were included in the "moss/lichen" category. Specimens of unknown species were collected and identified later. I then calculated average cover for each species (Robertson and Adams 1990), and the average number of species (species richness) per plot.

Table 2.1. Vegetation and soil characteristics of 9 sites with exclosures sampled in June - September 2002 in Jasper National Park, Alberta.

Site	Year Exclosure Established	Year Transects Marked	Soil Type	Elevation (m)	Slope (deg.)	Aspect (deg.)
Henry House	1956	1956	Loamy	1052	0°	0°
Moberly	1956	1956	Loamy	1062	0°	0°
Warden's Office	1988	2002	Loamy	1056	0°	0°
Cottonwood Point	1995	2002	Sandy	1106	25°	126°
Cottonwood Slough	1995	2002	Loamy	1140	5°	180°
Devona Hill	1995	2002	Sandy	1080	0°	0°
Edna	1995	2002	Sandy	1080	0°	0°
Windy Point	1995	2002	Sandy	1048	0°	0°
Richardson	2001	2002	Loamy	1041	0°	0°

In the second method, I estimated range condition, using the percent biomass method, as done previously by Tannas (1997), and these data are presented in Appendix B only. In the percent biomass method, green and cured vegetation totalled 100%, and a visual estimate of plant species composition by weight in each plot was recorded to 5% increments. I then calculated average % cover and range condition, where range condition is indicated by the total % of climax portion, or the total % of allowable species present (Wroe *et al.* 1988). In addition, I measured % litter cover and soil moisture in fenced and grazed areas (Appendix C).

Data Analyses

I used the Wilcoxon Matched Pairs test ($\alpha=0.10$) to test for the effects of grazing on species composition and richness by 2 soil types: sandy and loamy. Sandy sites included Edna, Devona Hill, Windy Point, and Cottonwood Point, while Cottonwood Slough, Henry House, Moberly, Richardson and Warden's Office were loamy sites. I presented statistical results only for vegetation classes and *Agropyron dasystachyum*, a major graminoid species.

To understand the relationship between grazing intensity and species richness across all sites, I regressed the average number of species against mean number of pellet groups counted in 2001 within 2 2-m x 30-m long transects at each site ($n=9$). Because of slow dung decomposition rates in Jasper grasslands, evident from the presence of old pellets in some exclosures erected in 1995 (*pers. obs.*), pellet groups present in 2001 reflected use over at least the past 5 years. I defined a pellet group as a group of ≥ 10 ungulate pellets. In addition, I plotted the difference between fenced and grazed species richness against pellet group counts for each site to show the effect of grazing on species richness.

To examine the long-term trends in grazed vegetation, I compiled data on plant composition taken in 1946 (Cowan 1946), 1952 (Banfield 1952), 1978 (Trottier 1979), and 1995 (Tannas 1997) at Devona Hill, Edna, Henry House, Moberly and Henry House (Appendix C). In 1946 and 1952, Cowan (1946) and Banfield (1952) used a diagonal 10-pin frame to express species cover as relative % frequency based on 100 point samples. In 1978, Trottier (1979) used the vertical point quadrat method, while in 1995, Tannas (1997) recorded both the vertical point quadrat method and % canopy cover methods, and

in 2002 I used the diagonal pin frame and % canopy cover methods. In 2002, I used a 10-pin frame in 4 plots per site, 2 inside the exclosure and 2 outside. I placed the pin frame 10 times within each Daubenmire frame, for a total of 100 pins per 0.1 m² plot. Each time the frame was set down, the total number of vegetation hits were counted until the pin hit the ground. Hits were recorded to species level, as well as hits on bare ground, moss/lichen, *Nostoc* spp., and litter. A hit was defined as any contact of vegetation with a pin, including multiple hits per individual plant or plant part. I converted pin counts to relative % frequency by dividing the pin count for each species by the sum total of counts (Tannas 1997).

I converted data on relative % frequency collected in 1946 and 1952 to % canopy cover using the following equation obtained by regressing my pin count data gathered in 2002 using a diagonal pin frame, expressed as relative % frequency, on % canopy cover data (see Appendix C for details):

$$\% \text{ Canopy cover} = 0.5856 (\text{relative \% frequency}) + 1.431 \quad (r^2=0.71, P<0.001, n=166)$$

I converted data on relative % frequency collected in 1978, using vertical pins, to % canopy cover using the following equation obtained by regressing data from Tannas (1997) relative % frequency, on % canopy cover data (see Appendix C for details):

$$\% \text{ Canopy cover} = 1.1242(\text{relative \% frequency}) + 0.6135 \quad (r^2=0.71, P<0.001, n=90)$$

All data were converted to % canopy cover using the above equations. I used the direct % canopy cover data from 1995 (Tannas 1997) and from my study in 2002. I grouped data into bare soil, grasses and sedges, *Artemisia frigida*, and "other forbs and shrubs" to facilitate the visual comparison of trends over time. I standardized canopy cover in all years by presenting the data as a percent of the total cover (100%). Statistical

analyses were not conducted on long-term data because I did not have access to raw data from previous studies.

To compare long-term vegetation changes with utilization trends, I compared pellet group counts for Henry House, Moberly, Edna, Devona Hill, and Windy Point in 1946 (Cowan 1946) to counts in 2001. I ranked the counts at each site for each of the two sampling periods, and compared them using a Spearman rank correlation ($\alpha=0.10$).

I tested the hypothesis that grasslands close to town received greater elk use than those further away by regressing the number of pellet groups on distance from the centre of the townsite. I conducted elk pellet group counts in August 2001 at 70 low elevation grassland sites, chosen from the Jasper Ecological Landform Classification. I used 1 2-m x 30-m long transect per location and counted the number of pellet groups within each transect.

Results

Effects of Grazing in 2002

Grazing generally reduced canopy cover of vegetation classes, although this effect was often contingent upon soil type (Table 2.2). Total vegetative cover ranged between 22.5% - 25.1% less in grazed plots than in fenced plots ($P=0.07$), in loamy and sandy soils respectively. In contrast, bare soil was 49.1% greater in grazed plots at sandy sites ($P=0.07$), but was not affected by grazing at loamy sites ($P=0.14$). Graminoids provided 13.9% greater cover in fenced plots at sandy sites ($P=0.07$), but were unaffected by grazing at loamy sites ($P=0.14$). Similarly, at sandy sites, forb cover was 10.2% greater in fenced plots than grazed ($P=0.06$), but was no different at loamy sites ($P=0.16$). While invasive forbs were negligible at loamy sites, Russian thistle (*Salsola*

Table 2.2. Mean (sd) percent canopy cover of major species and vegetation classes in July 2002 at 8 grassland sites¹ by soil type in Jasper National Park, Alberta.

	Sandy Sites				Loamy Sites			
	Fenced		Grazed		Fenced		Grazed	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
<i>Agropyron dasystachyum</i>	11.8	9.7	4.2	2.0	6.2	6.7	1.3	1.4
Invasive Graminoids	0.0		0.0		12.3 *	17.2	2.2	4.4
Total Graminoids	26.2 *	6.5	12.3	2.2	28.3	7.7	14.8	7.5
Fabaceae	1.5	2.4	0.1	0.2	6.4 *	2.8	5.3	2.4
Invasive Forbs	1.0 *	1.3	4.1	5.9	0.2	0.2	0.3	0.3
Total Forbs	23.9 *	5.8	13.7	4.6	28.5	6.0	22.3	6.3
Total Shrubs	2.6	3.5	1.6	2.9	4.2 *	3.5	1.1	1.7
Total Vegetation	52.7 *	4.7	27.6	8.3	60.8 *	4.8	38.3	8.0
Average No. Species	7.9 *	2.5	6.2	1.9	7.5 *	1.2	8.0	1.4
Bare Soil	9.0 *	10.9	58.1	6.5	3.4	3.0	27.8	18.0
Moss/Lichen	5.3	8.2	8.1	11.5	41.6	38.3	24.0	30.8
Litter	27.2 **	7.3	6.4	4.1	33.6 **	16.0	7.5	2.3
% Soil Moisture	13.8	1.2	10.8	3.1	29.7	7.0	26.5	6.7

¹ Excluding Richardson (established in 2001)

kali) was 3.1% greater outside exclosures than inside at sandy sites ($P=0.05$). In contrast, invasive graminoids were absent from sandy sites but at loamy sites, Kentucky bluegrass (*Poa pratensis*) provided 10.1% greater cover in fenced plots than grazed ($P=0.10$).

Although neither moss nor lichen were affected by grazing in either soil type, litter was between 10.8% - 26.1% greater inside exclosures ($P=0.04$), at sandy and loamy sites respectively. The effect of grazing on species richness was also contingent upon soil type, where species richness decreased with grazing at sandy sites ($P=0.07$) and increased with grazing at loamy sites ($P=0.07$). Species richness was negatively correlated with the number of elk pellet groups ($r^2 = -0.62$, $P=0.10$; Fig. 2.1A). Further, when I plotted the

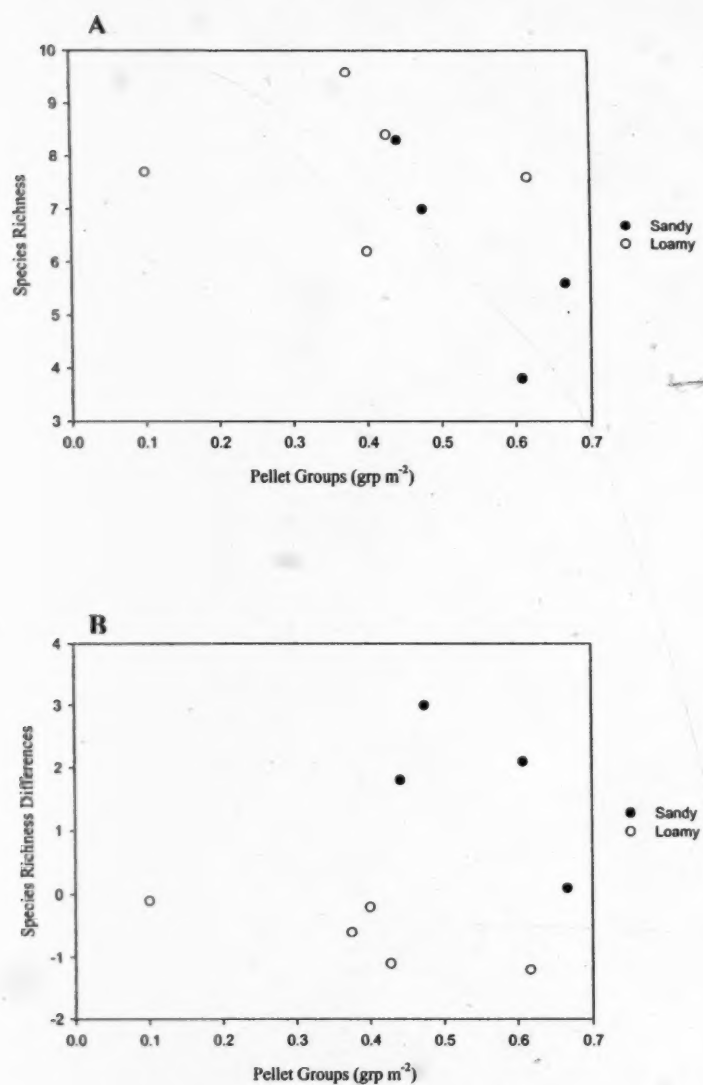


Fig 2.1. A) Association between species richness (number of species per plot) and pellet group densities, and B) difference in species richness between fenced and grazed plots against pellet group densities in 9 grasslands, Jasper National Park, Alberta.

difference in the number of species between fenced and grazed plots on different soil textures, I found that at sandy sites, grazing resulted in lower species richness relative to inside the enclosure ($P < 0.05$; Fig. 2.1A), while grazing at loamy sites resulted in greater species richness outside the enclosures than inside ($P < 0.05$; Fig. 2.1B).

I found a negative relationship between elk pellet group density and distance from the townsite ($r^2 = -0.25$, $P < 0.05$; Fig. 2.2), indicating that elk use is higher closer to the townsite. The distribution of elk pellets between seasons indicated that all sites are subject to winter and summer use (Fig. 2.3). In particular, Cottonwood Slough received greater use in summer than in winter.

Long-term Trends in Grazed Grassland

Although bare ground cover has generally decreased since 1946, overall vegetation cover has not changed greatly since 1946, with the exception of 1995, in which vegetation measurements tended to be higher than other years (Table 2.3). Vegetation cover values were highest in 1995, while measures 1946-1978 were similar and closely resembled results in 2002 (Table 2.3). Henry House was the only site where grass and sedge cover gradually increased between 1946 and 1978. Meanwhile, cover by *Artemisia frigida* did not increase at any site and showed a consistent decline across sites since 1946 (Table 2.3). In addition, there was no evidence for a reduction in forb and shrub cover since 1946, and as with graminoids, forb and shrub estimates in 1995 were higher than other years. I failed to find a significant Spearman correlation between pellet group rankings at these 5 sites in 1946 and 2001 ($r^2 = 0.10$; $P = 0.75$).

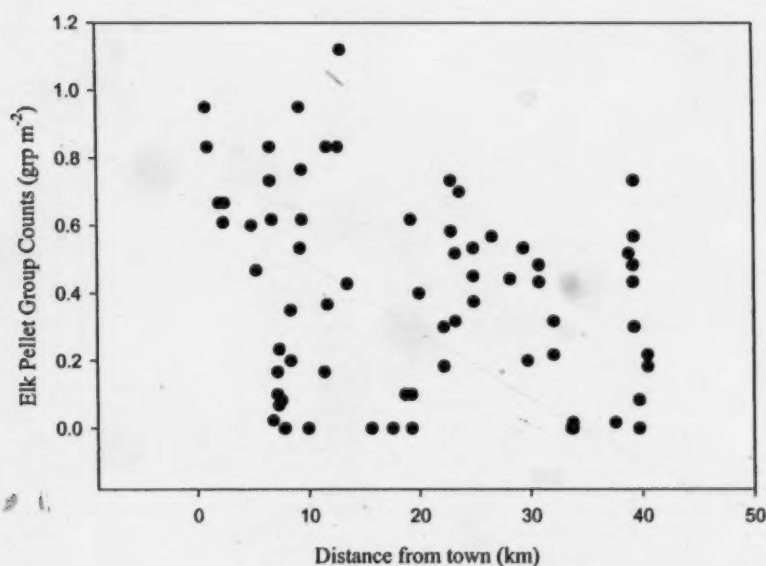


Fig 2.2. Relationship between elk pellet group density, measured in August 2001 from 70 grassland locations throughout Jasper, and distance from the centre of the town of Jasper, Alberta ($r^2=-0.25$, $P<0.05$).

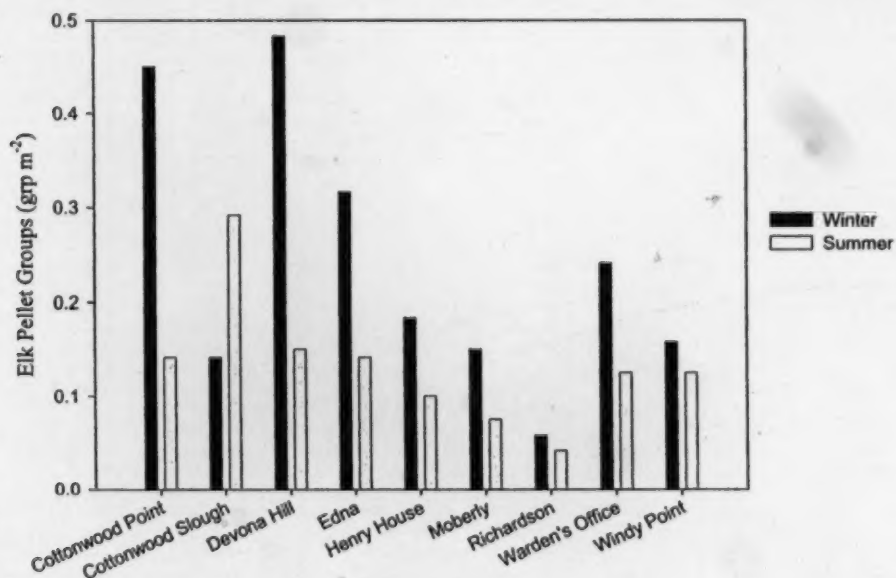


Fig 2.3. Winter and summer elk pellet group densities at 9 grassland sites in Jasper National Park, Alberta.

Table 2.3. Percent canopy cover of vegetation groups sampled from 1946-2002 at 5 sites in Jasper National Park, Alberta.

	1946	1952	1978	1995	2002
Devona Hill					
Grasses and sedges	4.8	7.8	---	58.6	10.9
<i>Artemisia frigida</i>	11.7	4.0	---	5.4	1.1
Other forbs and shrubs	7.6	6.1	---	35.2	18.2
Bare ground	75.9	82.0	---	12.2	62.2
Moss/Lichen	---	---	---	9.7	9.5
Litter	---	---	---	---	5.0
Edna (Talbot Lake)					
Grasses and sedges	11.3	10.8	---	44.7	14.6
<i>Artemisia frigida</i>	6.8	4.2	---	5.3	1.5
Other forbs and shrubs	4.1	5.3	---	41.8	14.9
Bare ground	77.7	79.7	---	20.3	30.4
Moss/Lichen	---	---	---	15.5	21.5
Litter	---	---	---	---	13.3
Henry House					
Grasses and sedges	14.4	13.7	36.7	57.2	25.6
<i>Artemisia frigida</i> ¹	7.8 ¹	10.5	18.0	19.4	14.0
Other forbs and shrubs	7.1	4.2	18.6	7.7	8.9
Bare ground	70.7	71.5	42.8	2.4	2.5
Moss/Lichen	---	---	41.4	2.8	20.3
Litter	---	---	16.4	---	26.7
Moberly					
Grasses and sedges	19.1*	18.3*	53.7	62.3	53.7
<i>Artemisia frigida</i>	---	---	4.0	5.4	4.0
Other forbs and shrubs	9.9*	10.4*	36.3	44.8	36.6
Bare ground	70.9*	71.3*	71.2	18.5	38.5
Moss/Lichen	---	---	13.3	9.0	27.9
Litter	---	---	2.3	---	5.7
Windy Point					
Grasses and sedges	4.5*	8.8*	---	43.5	13.8
Kinnickinnick	19.4*	17.8*	---	0.0	0.0
<i>Artemisia frigida</i>	---	---	---	9.3	8.8
Other forbs and shrubs	4.3*	4.8*	---	29.5	13.7
Bare ground	71.8*	68.6*	---	67.4	59.5
Moss/Lichen	---	---	---	9.0	1.8
Litter	---	---	---	---	7.3

* = Exclosure in different location than 1978 onwards.

¹ includes *Artemisia frigida* and *Antennaria* spp.

Long-term Effects of Grazing (1995-2002)

I compared differences in vegetation inside and outside exclosures in 1995 and 2002 to look at short-term effects of grazing. Since 1995, there has been little change in total fenced graminoid cover in sandy soils (Fig 2.4A). However, total forb cover inside exclosures may have increased with fencing since 1995, as has total vegetation cover. Similarly, shrub cover at sites with sandy soils has increased in fenced grassland relative to grazed. Fencing has also resulted in a strong decrease in bare soil cover. At sites with loamy soils, fencing has resulted in an increase of both total graminoid cover and invasive grasses since 1995 (Fig 2.4B). Invasive forbs, however, have either declined with fencing or increased in grazed grassland since 1995. Fabaceae forbs have increased with fencing, while overall forb cover has decreased relative to grazed grassland. Shrub cover has increased inside the exclosures since 1995, as has total vegetation and moss cover. Conversely, bare soil has decreased with fencing since 1995.

Discussion

I found no evidence of decreased vegetative cover since the 1940's, although Jasper's montane grassland ranges have not improved as much as might have been expected based on reduction in grazing pressure due to changes in ungulate population numbers. At least 2500 elk populated the Park in 1944 (Fig 2.5; Bradford 1999), but with the initiation of an elk culling program in 1945, elk numbers decreased to 800 individuals (Dekker *et al.* 1993, Bradford 1999). Although elk numbers increased since 1970, their populations are monitored and have not exceeded ~1500 individuals (*pers. comm.* G. Mercer, JNP). In addition, an average of 220 domestic stock, including horses and cattle,

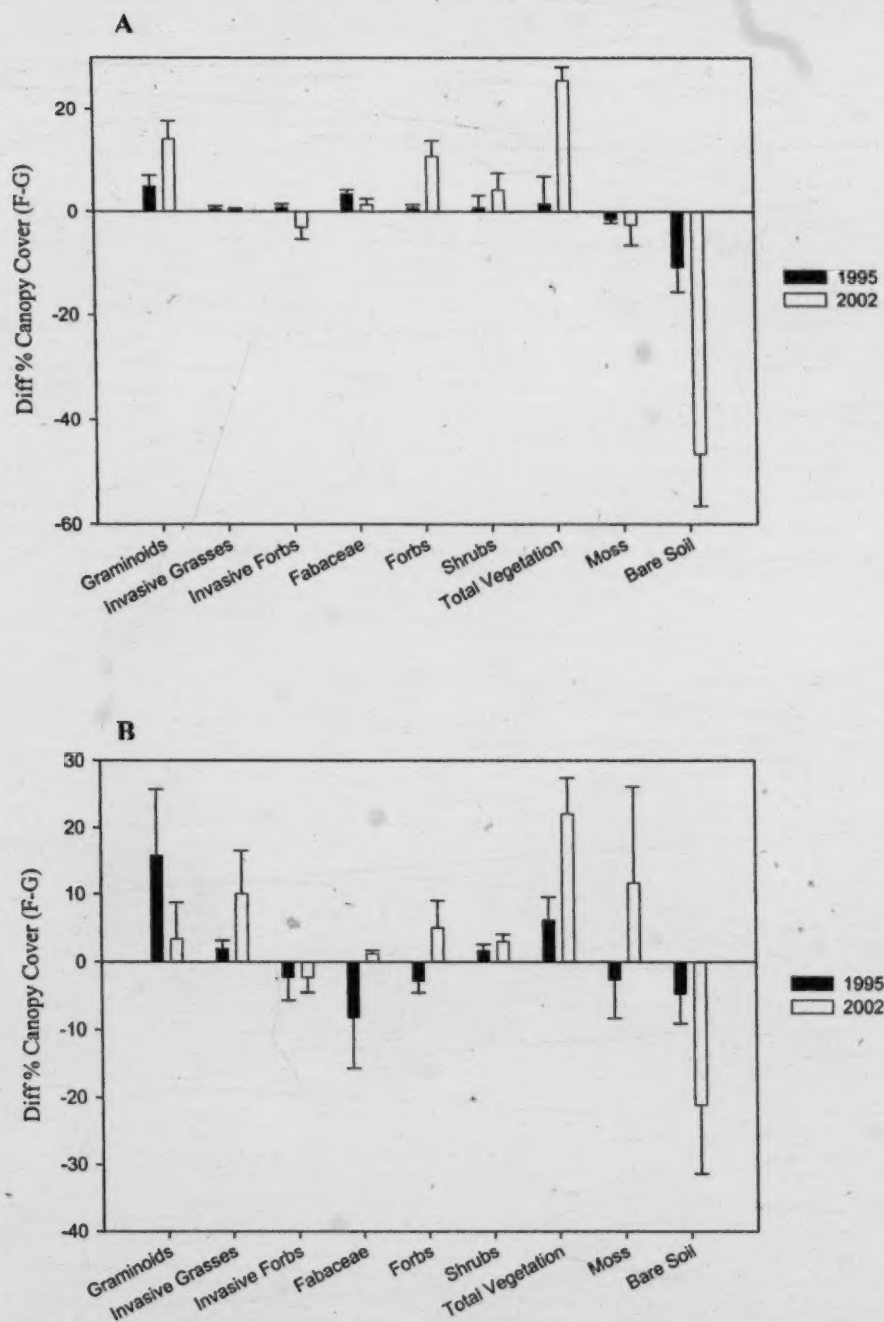


Fig 2.4. The difference (+SE) in % canopy cover of vegetative classes and bare soil between fenced and grazed plots at: A) sandy sites ($n=4$), and B) loamy sites ($n=4$) for 1995 and 2002 in Jasper National Park, Alberta. *indicates a significant difference between 1995 and 2002 within a vegetation class at $P<0.05$; ** $P<0.01$.

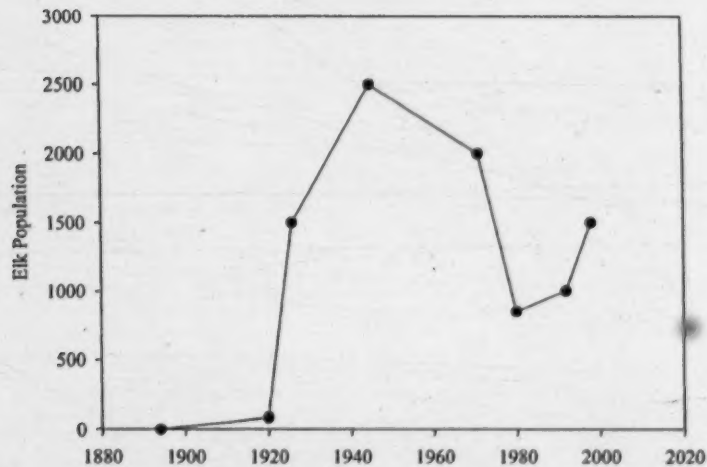


Fig. 2.5. Elk population trends in Jasper National Park, Alberta (1880's-2000)

grazed in the Athabasca Valley between 1934 and 1947, on ranges such as Henry House, Devona Hill, and Moberly (Pfeiffer 1948). Because vegetation surveys concluded that ranges overgrazed (Cowan 1946, Banfield 1952), horse grazing ceased in the early 1960's.

There are several reasons why greater improvement may not have occurred in low elevations grassland despite the reduction in ungulate numbers over time. First, I may have been unable to detect changes over time due to variability in vegetation survey methods. Although I used data gathered using similar methods to convert past data to percent canopy cover, 1995 values were high to due to inclusion of overlapping vegetation layers leading to totals >100%, and may have resulting in overestimation of 1978 values. It is also possible that high 1995 values were related to summer (May-July 1995) rainfall, which was 28% above the 60-year average of 133.6 mm (Appendix C), but snowfall the previous winter was 67% lower than the annual average. Although high 1995 cover estimates due to above average growing

season precipitation cannot be ruled out, I suggest interpretational differences by observers contributed most to these differences.

Second, range condition may have not improved greatly since the 1940's because these grasslands have always been key winter ranges and subject to heavy levels of herbivory, particularly with coniferous forest invasion and shifts in migratory behaviour since the 1940's. The exclosure sites themselves were originally selected on the basis of winter utilization, and were considered "as heavily utilized as any in the Park, and are therefore, excellent indicators of the ecological and productive status of the winter ranges in the Park" (Cowan 1946). Many of the grassland sites, however, have been subject to coniferous forest invasion since the 1940's, and since 1949, >48% of Jasper's grassland has succeeded to either open or closed forest (Rhemtulla 1999). Thus, today's elk may be being forced into smaller areas of grassland and thus lower total population numbers may be exerting similar grazing pressure as in the 1940's. In addition, seasonal pressure in grazing may have been extended into the summer due to reduced migratory behavior, thereby increasing grazing pressure on the grasslands. Year-round grazing has been found to reduce production in Wind Cave National Park (Detling 1998), because plants have insufficient time to recover before senescence (Holechek *et al.* 2001). Further, not only may higher year-round grazing occur on Jasper's grasslands, but ungulate use across seasons appears to be greater closer to town, suggesting that sites such as Cottonwood Slough now may be subject to even higher grazing pressure than in 1940's. Thus, a combination of high ungulate density, grassland contraction, and

year-round use may have prevented the continued poor condition of Jasper's grasslands.

Third, extreme climatic and edaphic conditions may have prevented the recovery of grazed vegetation in Jasper despite a reduction in ungulate population. Montane grasslands in Canada receive an average 515 mm of precipitation annually, ranging from 308 mm to 1279 mm (Willoughby 1997), compared with the average 385 mm received annually by Jasper's winter ranges. In fact, grasslands in the Jasper Lake and Snake Indian River areas of Jasper, including Devona Hill, Edna and Windy Point, receive <380 mm precipitation annually, the least of all areas within the Canadian Rocky Mountain parks (Janz and Storr 1977). Not only do the sandy sites, receive the lowest annual precipitation in Jasper (Janz and Storr 1977), but sandy soils also have low water-holding capacity, which Pfeiffer (1948) suggested contributed to the low organic matter, productivity, and resilience to grazing that he observed at these sites. Under such xeric conditions, plants are less able to recover from grazing (Holechek *et al.* 2001), especially when grazing limits the accumulation of litter (Trottier and Fehr 1982, Coughenour 1991), thereby increasing soil irradiation and warming the soil, leading to reduced soil moisture (Aber and Melillo 1991). Thus, the xeric conditions combined with litter removal cover may have contributed to the poor regrowth of plants following herbivory.

Although grazed grasslands communities do not appear to have changed substantively over time, comparisons of grazed grasslands with fenced exclosures in 2002 indicate several changes that would occur if low elevation grasslands in Jasper were to experience no herbivory. Sandy grasslands were unable to tolerate grazing as

well as the more mesic, loamy sites, as suggested by Pfeiffer (1948). For example, total vegetation cover increased by 22.5 – 25.1% with grazer exclusion, at loamy and sandy sites respectively, while bare soil decreased. Similarly, Trottier and Fehr (1982) found that after 38 years of grazer exclusion, graminoid cover within the Hillsdale enclosure in Banff was 28% greater than in grazed grassland. Also, in mixed grass prairie on chernozemic soils (versus solonchic), *Agropyron smithii* cover was 9% greater inside 70-year old enclosures (Willms *et al.* 2002). In contrast, forb cover responded differently to lower herbivory, depending on soil type, such that at sites with sandy soils, forb cover increased, while forb cover at loamy sites was unaffected by fencing. Similarly, the effect of grazer exclusion on species richness was dependent on soil type, such that fencing at sandy sites increased species richness, while at loamy sites species richness decreased with grazer exclusion. Milchunas and Lauenroth (1993) hypothesized that grazing in xeric grasslands reduces species richness, while in more mesic locations, grazing increases species richness, due to greater changes to canopy cover and interactions among species. These results suggest that grazing at xeric sandy sites may reduce vegetation cover and diversity and therefore, range condition, while grazing at more mesic, loamy sites increases diversity and range condition.

There is concern that the invasion of non-native species such as *P. pratensis*, found at loamy sites in Jasper, may alter the vegetation dynamics of the plant community, with the invasive species becoming part of the community. The state and threshold model suggests that grassland species composition moves to the point of stabilization with the invasive species, rather than succeed back to the original

community, following removal of the disturbance (Willoughby 1997, Laycock 1991). Trottier and Fehr (1982) found that in Banff, protection from grazing allowed litter to accumulate, creating a micro-environment favouring plant species more tolerant of cooler, moister growing conditions, such as *P. pratensis*. The "state and threshold model" suggests that since *P. pratensis* invaded fenced grassland in Jasper, the plant community may not succeed back to pre-invasion state, thus altering the natural community. To test this hypothesis, Moberly exclosure could be torn down, and herbivores allowed access to the *P. pratensis*, while creating more xeric conditions.

While exclosure studies can provide information on the long-term effects of grazing, they have limitations. First, Jasper's exclosure sites were not picked randomly. Instead the sites where exclosures were established in Jasper were selected on the basis of known high ungulate use (Cowan 1946). Although the sites were well-distributed throughout the Athabasca Valley, they were in fairly similar grassland types, and did not represent the range of grasslands in the Park. Further, vegetation inside exclosures does not necessarily represent a "natural state" because almost all grasslands have evolved under grazing pressure (McNaughton 1989). Response in vegetation in the initial years of exclosure from ungulate grazing may be useful to determine whether traditionally grazed plant communities may have passed a certain threshold, beyond which they are unlikely to return to the original (Laycock 1991). Conversely, fencing may permit the movement of a plant community to a new and different state than the original one, perhaps dominated by non-native species such as *P. pratensis*. I have showed, however, that exclosures are useful tools to help managers understand grassland vegetation dynamics with no large mammal

herbivory. It will be important to focus not only on comparisons between grazed and fenced vegetation, but also on long-term changes in grazed grassland and to find creative uses for ungulate exclosures.

Conclusions

There is little evidence to support the hypothesis that vegetative cover in grazed montane grasslands in Jasper has shown improvement with reduced ungulate populations since the 1940's, although this conclusion is predicated on the variability in measurements resulting from different observers and natural variability in space and time. However, neither is there evidence that grassland vegetative cover has deteriorated since the 1940's. The lack of change in grassland vegetation may be related to either climatic and edaphic conditions of these grasslands, or to constant grazing pressure despite ungulate population declines, due to contraction of grassland area with succession. Nevertheless, comparison of vegetative composition and cover inside and outside exclosures in 2002 indicated that grazing reduced vegetative cover and litter inputs to the soil system, while increasing bare soil and some invasive species. The effect of grazing on species richness and invasive species was dependent upon soil type, as was the magnitude of the effect of grazing on vegetative cover.

Management Suggestions:

It is clear from comparisons across time and between fenced and grazed vegetation that the winter ranges in this study are still heavily used, despite elk reductions since the 1940's. Heavy grazing is perhaps, not so much a result of high

elk numbers, but of the contracted area of grassland available to them. Because of their xeric nature, Jasper's grasslands are unable to sustain high levels of grazing. I therefore recommend that Park managers should:

- 1) Conduct prescribed burns on winter ranges to slow coniferous forest invasion and open up grassland, at the following areas:
 - a. Along Snaring Road, from Richardson to first gate
 - b. Henry House/Jackladder/Airfield
- 2) At the least, maintain exclosures at Richardson, Devona Hill, Edna, Henry House, Moberly, and Windy Point to preserve and add to the long-term data sets that exist for the latter 4 ranges. Explanatory signs need to be constructed for those exclosures lacking.
- 3) Conduct the following surveys at exclosure sites:
 - a. Pellet group counts in spring and fall each year in order to measure seasonal use and changes in grazing intensity over time.
 - b. Vegetation surveys every 5 years, following the precise methods outlined in this study. To further facilitate future research, the raw data of each survey should to be filed with all previous reports on these ranges.
- 4) To facilitate interpretation of vegetation changes on winter ranges, aerial or roadside elk population surveys need to be conducted at regular intervals, and the results made available for future research through effective data management.

- 5) Moberly exclosure could be torn down to study the effect of disturbance on *P. pratensis*, and learn how ungrazed plant communities respond to reintroduction of herbivores.
- 6) Vegetation surveys need to be conducted at all grasslands along Jasper Lake, to identify sites invaded by Russian thistle. Once problem sites are identified, Park managers need to aggressively manage the thistle, and mechanically remove the weeds by cutting or pulling, and remove prior to seeding in August and September, focussing on large patches of thistle upwind along the grasslands.

Reference List

- Aber, J.D., and J.M. Melillo. 1991. *Terrestrial Ecosystems*. Saunders College Publishing, USA.
- Banfield, A.F. 1952. Range studies, Jasper National Park. Canadian Wildlife Serv. Edmonton, Alberta. 14pp.
- Bradford, W. 1999. Report on the 1999 aerial census of elk along the Athabasca and Miette Valleys of Jasper National Park.
- Coughenour, M.B. 1991. Biomass and nitrogen responses to grazing of upland steppe on Yellowstone's northern winter range. *J. Appl. Ecol.* 28: 71-82.
- Cowan, I.M. 1946. General Report upon Wildlife Studies in the Rocky Mountain Parks. Can. Wildl. Ser. Report. 32pp.
- Dekker, D., W. Bradford, and J. Gunson. 1993. Elk andn wolves in Jasper National Park, Alberta, from historical times to 1992.
- Detling, J.K. 1998. Mammalian herbivores: ecosystem-level effects in two grassland national parks. *Wildl. Soc. Bull.* 26(3): 438-448.
- Environment Canada 2002. http://www.msc-smc.ec.gc.ca/climate/products_services/cdcd_iso_e.cfm.
- Flook, D.R. 1955. An appraisal of the elk situation in the Athabasca Valley of Jasper Park.
- Frank, D.A., and S.J. McNaughton. 1993. Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. *Oecolog.* 96: 157-161.
- Frank, D.A. 1998. Ungulate regulation of ecosystem processes in Yellowstone National Park: direct and feedback effects. *Wildl. Soc. Bull.* 26(3): 410-418.
- Holecheck, J.L., R.D. Pieper, and C.H. Herbel. 2001. *Range management principles and practices*. Prentice-Hall, Inc., New Jersey, USA.
- Janz, B., and D. Storr. 1977. *The climate of the contiguous mountain parks: Banff, Jasper, Yoho, Kootenay*. Parks Canada. Edmonton, Alberta.
- JNP. 2000. *Elk management plan: Jasper National Park*.
- Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands-a viewpoint. *J. Range Manage.* 45: 427-433.

- McNaughton, S.J. 1989. Interactions of plants in the field layer with large herbivores. Symposium of the Zoological Society of London 61: 15-29.
- Milchunas, D.G., W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecol. Monogr.* 63(4): 327-366.
- Pfeiffer, R.W. 1948. Some factors affecting the winter ranges of Jasper National Park. M.Sc. Thesis, University of British Columbia.
- Rhemtulla, J.M. 1999. Eighty years of change: the montane vegetation of Jasper National Park. M.Sc. thesis, University of Alberta.
- Robertson, A., and B.W. Adams. 1990. Two Worksheets for Range Vegetation Monitoring, Range Notes Issue No. 8 Range Management – Public Lands Division – ISBN 0-086499-654-3.
- Stringer, P.W. 1969. An ecological study of grasslands at low elevations in Banff, Jasper, and Waterton Lakes National Parks. Ph.D. Thesis, University of Alberta.
- Tannas, C.A. 1997. Analysis of range exclosures, Jasper National Park 1995. Parks Canada. pp 79.
- Trottier, G. 1979. Analysis of range exclosures, Jasper National Park 1978. Canadian Wildlife Serv., Edmonton, Alberta. pp.66
- Trottier, G., and A. Fehr. 1982. Re-evaluation of four range exclosures in Banff National Park, 1981. Canadian Wildlife Serv. Edmonton, Alberta.
- Willms, W.D., J.F. Dormaar, B.W. Adams, and H.E. Douwes. 2002. Response of the mixed prairie to protection from grazing. *J. Range Manage.* 55(3): 210-216.
- Willoughby, M.G. 1997. Rangeland reference areas: Castle River range condition and trend from 1953-1995. Environmental Protection Land and Forest Services. Edmonton, Alberta.
- Wroe, R.A., S. Smoliak, B.W. Adams, W.D. Willms, and M.L. Anderson. 1988. Guide to range condition and stocking rates for Alberta Grasslands 1988. Alberta Forestry, Lands and Wildlife, Edmonton.

CHAPTER 3

The Effect of Herbivory and Soil Texture on Carbon and Nitrogen Dynamics in Montane Grasslands of Jasper National Park, Alberta

Introduction

In Jasper, elk (*Cervus elaphus*) have been migratory and follow the phenological development of vegetation from restricted, low elevation winter ranges to summer ranges distributed across the landscape (JNP 2000; Frank 1998). There was concern in Jasper National Park, however, that the development of Jasper town had created a predator refuge where elk remained year-round, taking advantage of easily accessible vegetation (JNP 2000). Possible changes in elk distribution caused concern for the degradation of native grasslands near the townsite (JNP 2000). Concern over grassland degradation was exacerbated by conversion of grassland to coniferous forest due to lack of recent fires. In fact, since 1949, >48% of Jasper's native grassland has succeeded to either open or closed forest (Rhemtulla 1999). If Jasper's grasslands evolved primarily with winter and/or spring grazing, then heavy year-long grazing may alter grassland composition and carbon/nutrient flow of these systems, and potentially effect their long-term sustainability. Further, the effects of ungulate grazing on grassland carbon and nutrient dynamics are contingent on factors such as slope position and soil type (Burke *et al.* 1989, Frank *et al.* 1994, Frank and Groffman 1998, Tracy and Frank 1998). Interactions between herbivory and soil characteristics may be important determinants of the spatial patterns in nutrient dynamics across these grasslands.

Most grassland studies in Jasper National Park addressing grazing in grasslands have focused on plant species composition and diversity (Cowan 1946, Pfeiffer 1948, Banfield 1952, Stringer 1969, Trottier 1979, Tannas 1997). Collectively, these studies

have shown that grazing reduces total vegetation and litter cover, increases bare soil and invasive forb cover and reduces species richness on sandy soils, while increasing it on loamy grasslands (Chapter 2). In contrast, none of the previous studies conducted in grasslands of Jasper National Park have addressed changes in root biomass with grazer exclusion, and only one study measured the effects of grazing on soil characteristics (Stringer 1969). Stringer (1969) compared soil temperature, soil moisture, and total organic C inside and outside 3 exclosures established 13 years earlier. Relative to inside the exclosures, soil temperature averaged 5.2% higher and soil moisture 66% lower with grazing, but total organic C was unaffected. He concluded that after 13 years of large herbivore exclusion, plant cover and standing crop had increased, but that these changes were not yet reflected in soil characteristics, particularly at the xeric Henry House site.

Nevertheless, extensive research in other semi-arid grassland systems has documented that grazing can alter C and N flows depending on timing and intensity of grazing. For example, aboveground standing biomass has been found to increase with winter or spring grazing by an average 48% in Yellowstone National Park (Frank and McNaughton 1993). Increased productivity with grazing has been attributed to increased light penetration with litter and canopy removal (Monsi *et al.* 1973), allocation of C to aboveground plant structures (Gold and Caldwell 1989), and, therefore, higher rates of photosynthesis (Oosterheld and McNaughton 1988). Repeated grazing throughout the growing season, however, ultimately reduces aboveground production (Holland and Detling 1990, Willms *et al.* 1990). Because many plants allocate a greater proportion of their available C to aboveground structures than to belowground biomass with defoliation (Holland & Detling 1990), root biomass may decrease in response to defoliation. For

example, Engel *et al.* (1998) found that a single June clipping reduced sand bluestem (*Andropogon hallii*) root length and weight by 16% and 14%, respectively, while multiple clippings reduced root length and weight by 43% and 33%, respectively. Similar declines in root biomass have been reported from field studies of year-round grazing in both Wind Cave (Holland and Detling 1990) and the mixed prairie (Willms *et al.* 1990), but were not found in Yellowstone where ungulates are migratory, except in a drought year (Coughenour 1991). Because most of the readily available organic C used by microbes is derived from plant materials, plant production should constrain microbial biomass. This is supported by a positive correlation between plant and microbial biomass across ecosystems (Holland and Detling 1990, Tracy and Frank 1998, Cardon *et al.* 2002). In Yellowstone, plant biomass accurately predicted microbial biomass, and chronic grazing by ungulates neither depleted available soil C nor reduced microbial biomass (Tracy and Frank 1998).

Two reasons have been proposed for why microbial populations may be sustained with grazing in grasslands. First, aboveground defoliation has been found to induce root turnover and exudation (Holland *et al.* 1996), which provides a flush of readily available C and amino acids that supports rapid microbial growth (Cardon *et al.* 2002, Hamilton and Frank 2001). In addition, Hamilton and Frank (2001) found that increased microbial activity, net N mineralization, resulting from root exudates, was associated with elevated N uptake, shoot N, and rates of photosynthesis. An increase in net N mineralization reflects a greater increase in gross N mineralization than in N immobilization, and implies that N is being moved from a less active SOM pool to the more active microbial

biomass N pool (Hassink *et al.* 1997), where it can be readily taken up by plants (Cardon *et al.* 2001).

Thus, defoliation by large herbivores in winter or spring may increase active soil C and promote microbial growth, activity and plant recovery (Cardon *et al.* 2002). In contrast loss of root biomass with year-round defoliation may reduce available soil C (Willms *et al.* 1990, Holland *et al.* 1992, Biondini *et al.* 1998) and inhibit microbial growth (Holland and Detling 1990) and net N mineralization. Alternatively, where soil moisture is not limiting, year-round defoliation could provide microbes with continual pulses of readily available C and N, thereby sustaining microbial biomass and activity even with frequent grazing. When defoliation is accompanied by dung deposition, an additional source of C and N, with a low C/N ratio, is provided for microbes (Ruess and McNaughton 1987). Dung deposition has been found to maintain microbial biomass and to increase net N mineralization rates (Ruess & McNaughton 1987; Frank and Evans 1997; Tracy and Frank 1998), despite reductions in root biomass (Tracy and Frank 1998) thus increasing available mineral soil N for uptake by plants.

Soil characteristics also have an effect on C and N dynamics (van Veen *et al.* 1984, Rutherford and Juma 1992, Hassink *et al.* 1993, Groffman *et al.* 1996) and may alter the effects of grazing (Tracy and Frank 1998). In grasslands limited by N availability, plant production tends to be lower on sandy soils compared to areas with more finely-textured soils (Frank and Groffman 1998, Lane *et al.* 1998). Grazing should reduce standing aboveground biomass and root biomass most where production is greatest because there is more opportunity for herbivores to impact the vegetation on more productive sites (Milchunas and Lauenroth 1993, Willms *et al.* 2002). Relative to

xeric, unproductive areas, aboveground defoliation in productive areas will have a greater relative effect on both canopy cover and the percentage removal of total plant biomass, and will therefore alter the intensity of plant interactions to a greater extent (Milchunas and Lauenroth 1993).

Microbial biomass is higher in loamy soils than sandy soils not only because of higher productivity (Tracy and Frank 1998), but because of the greater physical and chemical protection in fine-textured soils (Hassink *et al.* 1993, Hassink *et al.* 1997). Fine-textured soils tend to provide microbial biomass greater physical protection from predation than coarse-textured soils, because of smaller pore diameter (Hassink *et al.* 1997). In sandy soils, however, microbes are protected from predation and organic matter from decomposition by adsorption to clay particles (Hassink *et al.* 1997). Hassink *et al.* (1997) found that microbial biomass was equally protected in coarse- and fine-textured soils, but in fine-textured soils, bacteria are additionally located within small pores within soil aggregates, resulting in greater overall microbial biomass. Tracy and Frank (1998) found that soil texture had more of an effect on microbial biomass than grazing, possibly because of inputs of C from dung deposition and increased root exudation, and that there was no interactive effect of grazing with soil type. Thus, dung inputs may have an equal effect on both fine- and coarse-textured soils, resulting in no change in microbial biomass with grazing on either soil type. Net N mineralization rates, however, are higher in sandy soils due either to more rapid microbial turnover or greater organic C (dung) availability resulting from lower physical and chemical protection decomposition (Rutherford and Juma 1992, Hassink *et al.* 1993). In Yellowstone, grazing stimulated net N mineralization mainly in topographic depressions with fine-

textured soils, and least at slope tops where soils were xeric and coarse-textured (Tracy and Frank 1998) because microbial populations in more productive sites were both larger and more active.

In this study, I examined the effects of defoliation and soil type on above- and below-ground plant production, microbial biomass, net mineralization rates and total mineral N pools in the low elevation grasslands of Jasper National Park. To address the concern of increasing numbers of elk remaining on winter ranges year-round, I conducted an experiment that imposed 2 years of 3 clipping treatments mimicking winter-only, winter/spring, and year-round ungulate grazing on grassland vegetation within 9 exclosures established between 1956 and 2001, and compared to naturally grazed treatments outside exclosures.

I hypothesized that winter-only defoliation would have no effect on total production, root biomass, microbial biomass and activity, or mineral N. On the other hand, I predicted that winter/spring defoliation would increase total production over the growing season. Clipped plants are known to have higher regrowth rates than unclipped control plants (Oosterheld and McNaughton 1988). I expected root biomass to decrease in the spring in response to greater aboveground regrowth rates, but to recover by fall. Conversely, microbial biomass should increase in spring in response to spring clipping and root loss, and have greater net N immobilization, but should drop to control levels by fall. Therefore, I expected to see a reduction in available mineral N in the soil in the spring that would not be evident in the fall.

I predicted that year-round defoliation would have the same effect as winter/spring clipping in the spring, but in the fall, however, both aboveground

production and root biomass should be the lowest of all treatments due to repeated defoliation. I expected that microbial biomass would still be higher than control, unless root biomass had decreased. If roots were not reduced in the fall, net N mineralization and mineral N would increase; if roots were reduced, I expected net N immobilization to increase and mineral N to decrease.

I measured the same plant and soil variables outside the exclosures. I hypothesised that grazing would reduce both total production and root biomass, but that microbial biomass would be maintained and increase with intensity of grazing. Dung has been found to provide a N-rich substrate for microbes, resulting in increased net N mineralization and mineral soil N with grazing. If grazing occurs in the winter and the spring, I expected that aboveground biomass and root biomass would increase towards ungrazed levels by fall, while dung may continue to effect microbial biomass and activity into the fall.

Because 4 of the 9 exclosures were on sandy soils and five were on loamy soils, I examined the effects of soil type on the above predictions. I expected sandy soils should have lower microbial biomass, greater net N mineralization rates, and increased mineral N leaching than loamy soils. Coarse textured soils tend to have lower physical and chemical protection capacity, as well lower water-retention capacity (Hassink *et al.* 1997).

Methods

Defoliation Treatments

In winter 2001, I established 8 2.5-m² treatment plots within 9 exclosures and 2-3 plots outside the exclosure. Plots inside the exclosures were 0.5 m apart on the ends and

1.0 m apart on the sides, while plots outside the exclosure were placed 5, 10 or 15 m from the exclosure in a random direction. To minimize the effects of adjacent plots, I used a turf edger to sever rhizomatous connections around the edges of the plots in May of 2001 and again in 2002. Three clipping treatments, including winter, winter/spring, year-round, and an unclipped control, were randomly assigned to plots inside each exclosure, while plots outside the exclosure were exposed to natural grazing. In 2001, winter clipping occurred February 17-26 at 7 sites, but clipping was delayed until 26 April at Warden's Office and Cottonwood Slough due to thick snow (Appendix D). Winter clipping in 2002 occurred January 7-11, except at Cottonwood Slough where clipping occurred on 28 April. Spring clipping treatments occurred May 23-28 in 2001 and May 14-20 in 2002, while summer clipping was performed twice each year, June 20-25 and July 20-28 in 2001, and June 19-25 and August 18-24 in 2002. Clipping in 2002 was delayed because I conducted vegetation surveys in July 2002 (Chapter 2). At Henry House, vegetation was not clipped a second time in summer 2001 or 2002 because vegetation had not regrown since the previous clipping. Vegetation was clipped to 10 cm in height in 2001, and to 5 cm in 2002, according to the height of naturally grazed vegetation. Plots were clipped at Richardson although the exclosure was not established until July 2001, while Edna had only 3 control plots and 3 natural grazing plots.

Aboveground biomass

In 2001, I estimated aboveground green biomass in May 15-21 and August 20-28, while in 2002 green biomass estimates occurred in May 8-17 and September 1-9. To estimate standing green biomass in each treatment plot, I used a pin sampler, a frame holding 10 long pins extending to and conforming to ground level (Cowan 1946). Each

time a pin was passed through the vegetation to the ground, the number of green vegetation hits was counted. A hit was defined as any contact of green vegetation with a pin. I placed the pin frame 10 times within a permanently marked 0.10-m² microplot in each larger treatment plot, for a total of 100 pins per plot. To convert pin counts to biomass, I performed pin counts at 1-2 random locations outside each enclosure at each sampling period, and destructively sampled these 0.10-m² plots to obtain estimates of standing green and dead biomass. Clipped vegetation was separated into green and cured standing biomass, oven dried at 70° C and weighed to the nearest 0.01 g.

I regressed green biomass (g m⁻²) on pin counts and obtained the following equation, which was used to convert pin counts to green biomass:

$$\text{Green Biomass (g m}^{-2}\text{)} = 6.46 + 0.428 * (\text{Pin Counts}); (r^2=0.84, P<0.001, n=109).$$

In May and September 2002, I also visually estimated the percent cover of total standing vegetation (green and dead), standing dead vegetation, and litter (fallen vegetation) within each 0.10-m² microplot. Total production was measured in August 2002 by summing the biomass of green and standing dead plant material in August with the biomass of clipped or grazed vegetation over the growing season.

I calculated the proportion of available standing biomass removed in each clipping treatment in 2002 by adjusting green biomass to a total standing biomass (green plus standing dead material) using the ratio of standing dead to green biomass based on data from the destructively sampled plots of 2002. I used a ratio of 1.89 ± 1.21 (mean $\pm$ SD) in spring (May), a ratio of 6.24 ± 7.08 in June, and a ratio of 2.38 ± 1.48 in fall (August; Appendix D). I then divided the amount of standing biomass present a week

prior to clipping, by the biomass of vegetation removed in the clipping treatments and multiplied by 100 to obtain a percentage.

Root Biomass

The top 5 cm of soil was sampled in June 20-25 and October 1-9 2001 and June 19-25 and October 8-17 2002 for root biomass in each treatment plot. I took 2-3 soil cores (4.5 cm diameter, 284 cm³) from each 2.5m² plot, keeping the cores on ice in the field until they could be frozen. Due to time demands for processing roots, samples were frozen for up to 6 months prior to analyses. A root washer with a 4-mm sieve separated roots from soil. Using tweezers, roots of all sizes caught by the 4-mm sieve were separated from organic matter, including partially decomposed plant matter, moss, crowns, and wood. These roots were then scanned for length, using an Epson scanner and WinRhizo computer package (WinRhizo 2000). Roots and organic matter were dried separately for 48 hours at 50°C, and weighed to the nearest 0.001 g. I did not process root samples from Richardson in fall 2001 because of time limitations.

Microbial biomass carbon and nitrogen

With the exception of fall 2001, I determined microbial biomass C and N in the top 0-5 cm of soils collected in June 20-25 2001, June 19-25 and October 8-17 2002, from the PVC tubes used for *in situ* N mineralization incubation (see below). I did not determine microbial biomass C and N in fall 2001 because of an error in the laboratory incubation procedure. Soil samples were composited within a plot and put through a 2-mm sieve to remove roots, which could serve as a potential C source during chloroform-fumigation-incubation (Martens 1995). Soils were refrigerated to avoid microbial death (Anderson and Domsch 1993), and analyzed <14 days following field collection.

Gravimetric soil moisture and field capacity were determined by drying soils for 24 hours at 105°C. Soils were brought to 80% field capacity prior to starting the CFI experiment. I used ~12 g of soil to determine initial NH_4^+ and NO_3^- , which was later subtracted from the incubation N to determine microbial N (Robertson *et al.* 1999).

I followed the chloroform-fumigation-incubation procedure of Robertson *et al.* (1999) to obtain estimates of microbial biomass. I measured ~25 g of soil into glass beakers and subjected these soils to a 24-hour chloroform fumigation. To serve as my control, ~40 g of soil was placed into plastic cups and refrigerated until the fumigation was complete. Each soil sample was placed in a canning jar along with 10 mL of de-ionized water, and 25mL of 0.25 N NaOH to serve as the CO_2 trap. Samples were incubated in the dark, at cool room temperature for 10 days. Upon completion of the incubation, I performed a back-titration of the unreacted NaOH using 0.1 M HCl, 2 mL of 2 M BaCl_2 solution, and several drops of 1% phenolphthalein indicator. Following incubation, final NH_4^+ and NO_3^- pools were determined using ~12 g of the fumigated and control soils. Microbial biomass C and N were calculated following the formulae provided by Robertson *et al.* (1999:pp 304-305). These formulae assume that the k_c value is 0.41 (Robertson *et al.* 1999) or that 41% of the biomass C is mineralized during the 10-day incubation (Voroney and Paul 1984), and that the incubation temperature is constant for both control and fumigated samples. Microbial biomass C and N were expressed on the basis of per gram soil used for the incubation.

Soil mineral N and net N mineralization rate

In situ estimates of net nitrogen (N) mineralization rates were obtained for the periods: September 1-5 to September 29/October 9) in 2001, May 21-26 to June 19-25

2002, and September 10-17 to October 8-17 2002, following the procedures of Jaeger *et al.* (1999). Two or three PVC tubes (17 cm long, 5 cm wide) were driven into the ground within each treatment plot at a location randomly selected using a grid system, and left for ~28 days. A paired sample was taken from a randomly chosen location ≤ 20 cm from the PVC tube at the time the incubation tube was placed in the ground. Except in spring 2001, soil cores within these PVC tubes were separated into the top 0-5 cm of soil and bottom 5-15 cm, placed in plastic zip-loc bags, and kept on ice while in the field. Soil samples were composited by plot into the top 0-5 cm, and bottom 5-15 cm. Rocks and coarse root fragments were removed, but because their volume was not taken, N variables were expressed on a per gram basis (Raison *et al.* 1987), not on a metre-squared basis. Samples were kept frozen until laboratory extraction of NH_4^+ and NO_3^- with 2 M KCl.

Gravimetric soil moisture for each composited sample was determined by drying soils for 24 hours at 105°C (Raison *et al.* 1987). I averaged the soil moisture taken from the initial sample and PVC tube sample (i.e. May and June, or September and October)

In spring 2002, I added resin bags on the bottom of the PVC tubes (Zou *et al.* 1992) to measure N leaching. Resin bags were constructed by cutting nylon stockings into ~7 x 20 cm lengths, and using a glue gun to close one end of the "bag". I filled each bag with ~17 g of mixed-bed ion exchange resin, and glued shut the open end of the bag. PVC tubes were driven into the ground, pulled back out, and the bags fastened onto the bottom of the incubation PVC tubes with rubber bands. The tubes were put back into the ground and left for ~28 days. I composited the resin samples within each plot and kept them frozen until laboratory extraction of NH_4^+ and NO_3^- with 2 mol/L KCl. Leached N was reported as quantity of N per unit of resin.

Vegetation Utilization Estimates

To measure monthly offtake by large herbivores in the grassland surrounding each enclosure, I selected 5-7 paired sites (≥ 4 m apart) and placed a moveable, 1-m³ cage over 1 of the plots chosen at random (Frank and McNaughton 1992). Each month from May to October, 3 0.10-m² Daubenmire plots within the larger 1-m² plots were destructively sampled, vegetation separated into forbs and grasses, and the pairs of plots moved to another random location at the same site. No distinction was made between live and dead plant material, although only standing vegetation was sampled. Vegetation was then dried for 24 hours at 70° C and weighed. To estimate winter use, cages were left in place from October – early May. Offtake was calculated for each paired plot by summing the clipped vegetation from the 3 Daubenmire plots within each 1-m² plot, then taking the difference between caged and grazed vegetation biomass (Frank and McNaughton 1992). I averaged the differences across the 5-7 paired plots per site and divided by the number of days the cages were in place to obtain offtake per day for grasses, forbs, and total vegetation (Frank and McNaughton 1992). I then calculated the proportion of available standing plant material removed by herbivores by dividing the difference between total fenced biomass and grazed biomass by fenced biomass, expressed as a percentage (Jasmer and Holechek 1984).

In addition to offtake, I counted and cleared pellet groups in May and October of 2001 and 2002. At each of the 9 sites, I established two 30 x 2-m long transects, within 25 m of the enclosure, placed such that they crossed at 90° at the 15-m mark. A pellet group was defined as a group of >10 pellets, and were included if more than half the pellets of a group fell within the transect. Pellet groups of elk, deer, and sheep were

counted. After counting was completed, transects were cleared of all pellet groups to make more accurate short-term use estimates.

Statistical Analyses

To test for differences in vegetation, microbial, and soil nutrient responses to defoliation treatments, soil type, and their interactions, I first used a 2-way ANOVA (Statistica, Statsoft, Inc. 1999) by year and season. I did not use repeated measures for this analysis because I expected that there would be *carry over* effects due to previous treatments (Zar 1996:263). In addition, I used a paired t-test to test for seasonal differences in vegetative, microbial, and soil characteristics within soil type and defoliation treatment. I also used a 2-way ANOVA by year and season to test for differences between responses in control inside the exclosure and naturally grazed plots only. Because few differences in the above analysis were attributed to defoliation treatment, I used a repeated-measures ANOVA across clipping treatments to test for the effects of year, season and soil type and their interactions on vegetative, microbial, and soil nutrients. When data were missing for a particular season (e.g. microbial C and N in fall 2001; mineralization in spring 2001), I did not test for seasonal differences. For all tests, I considered $\alpha = 0.10$ as statistically significant.

To determine relationships among vegetative, microbial and soil nutrients at a site, I related measures of these variables using population-averaged models for cross-sectional time series analysis (Xtgee, STATA 7.0, Stata Corp.) because I repeatedly sampled these characteristics at the same sites across time. I used a similar approach to relate soil characteristics to pellet counts outside the exclosures. Utilization data were not

statistically analyzed because of small sample sizes.

Results

In May 2002, spring clipping resulted in removal of between 15.8 and 72.6% ($36.2\% \pm 6.6\%$; mean $\pm$ SD) of total production. With the first summer clipping in June 2002, I removed 13.7 – 43.7% ($28.0\% \pm 5.3\%$) of total standing biomass, while the second summer clipping in August 2002 removed 3.4 – 27.2% ($12.0\% \pm 4.0\%$) of production. I was unable to calculate the proportion of biomass removed in winter because I did not record total standing biomass in winter. In May 2002, ungulates removed between 18.5 – 58.8% ($33.7\% \pm 7.8\%$) of available production at sandy sites, and between 23.8 – 41.2% ($30.4\% \pm 2.1\%$) at loamy sites, while in June 2002, herbivores removed 22.0 – 58.7% ($38.8\% \pm 6.2\%$) of available production at sandy sites and between 16.0 – 41.0% ($29.6\% \pm 4.0\%$) at loamy sites. In August 2002, herbivores removed 7.5 – 50.3% ($20.9\% \pm 8.4\%$) of the standing biomass at sandy sites, and up to 12.6% ($7.3\% \pm 2.3\%$) at loamy sites. Pellet group densities were 43.8% higher at sandy sites than loamy, while winter counts were 94.0% higher than pellet counts in summer (Table 3.1).

Table 3.1. Pellet group densities along 2 30-m² transects at 9 sites in Jasper National Park, Alberta.

	2001				2002			
	Winter		Summer		Winter		Summer	
	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy
$\bar{x}$	0.48 ^c	0.44 ^{bc}	0.31 ^b	0.16 ^a	0.35 ^b	0.16 ^a	0.14 ^a	0.13 ^a
sd	0.12	0.22	0.13	0.11	0.15	0.07	0.01	0.1
n	3	5	4	5	4	5	4	5
<i>P</i> -values	Year	Season	Soil	Yr*Se	Yr*S	Se*S	Yr*Se*S	
	0.00	0.00	0.10	0.44	0.99	0.91	0.17	

Pellet group counts were significantly related only to microbial biomass and had a negative relationship ($r^2=-0.35$; $P=0.072$; Fig 3.1). Microbial biomass was positively related to standing aboveground biomass ($r^2=0.44$; $P=0.01$; Fig 3.2), while having a positive relationship with root biomass ($r^2=0.23$; $P=0.095$; Fig 3.3). Finally, net N mineralization rate was negatively related to standing aboveground biomass ($r^2=-0.46$; $P=0.011$, Fig 3.4).

Vegetative and soil responses to defoliation treatments were highly variable and showed no significant effects on any plant or soil characteristics in any year or season (Tables 3.2-3.5). Neither standing green biomass ($20 - 73 \text{ g m}^{-2}$) nor root biomass ($52 - 223 \text{ g m}^{-2}$) were different among treatments, but root biomass was between 60 – 92% greater than aboveground green biomass (Tables 3.2 and 3.4). Similarly, microbial biomass C ($680 - 1174 \text{ ug C g}^{-1}$) and net N mineralization rate ($-0.06 - 0.22 \text{ ug N g}^{-1} \text{ day}^{-1}$) was no different among treatments (Tables 3.3 and 3.5). While soil moisture was unaffected by defoliation, values were generally low, ranging from 5.8 – 28.0% (Tables 3.3 and 3.5).

When I compared only control plots inside the exclosures to grazed plots outside the exclosures, I found that in spring 2002, standing dead vegetation cover in control plots ($15.9\% \pm 9.7\%$) was greater ($P=0.06$) than grazed ($6.7\% \pm 7.2\%$), and litter cover in control plots ($32.7\% \pm 19.4\%$) was greater ($P=0.06$) than grazed ($16.6\% \pm 11.0\%$). Similarly, in fall 2002 standing dead vegetation cover in control plots ($24.5\% \pm 18.9\%$) was greater than both grazed plots ($8.1\% \pm 8.7\%$; $P=0.009$) and winter/spring clipped plots ($7.0\% \pm 2.9\%$; $P=0.007$), and litter cover in control plots ($29.2\% \pm 14.2\%$) was greater ($P=0.04$) than grazed plots ($13.8\% \pm 11.6\%$). Lastly, I found that in fall 2002,

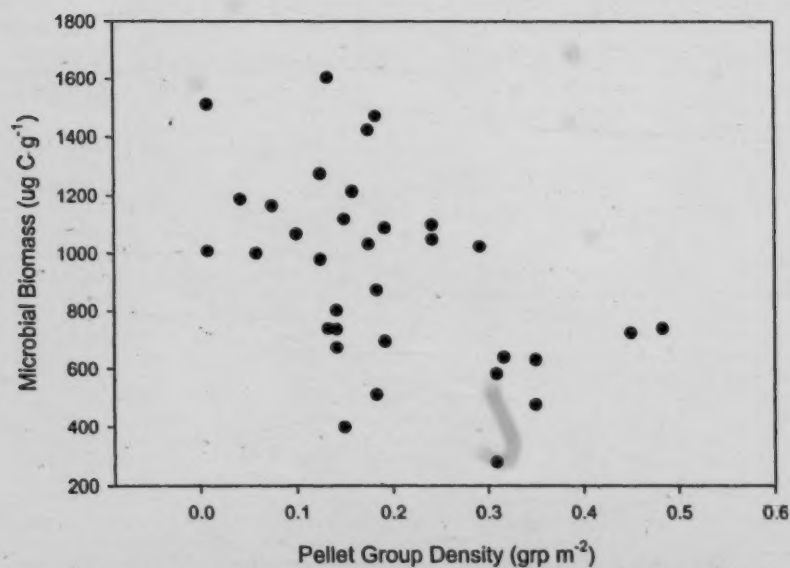


Fig 3.1. Relationship between microbial biomass C ($\mu\text{g C g}^{-1}$) pellet group density (groups m^{-2}) at 9 sites in Jasper National Park, with 4 sampling periods ($r^2=-0.35$; $P=0.072$).

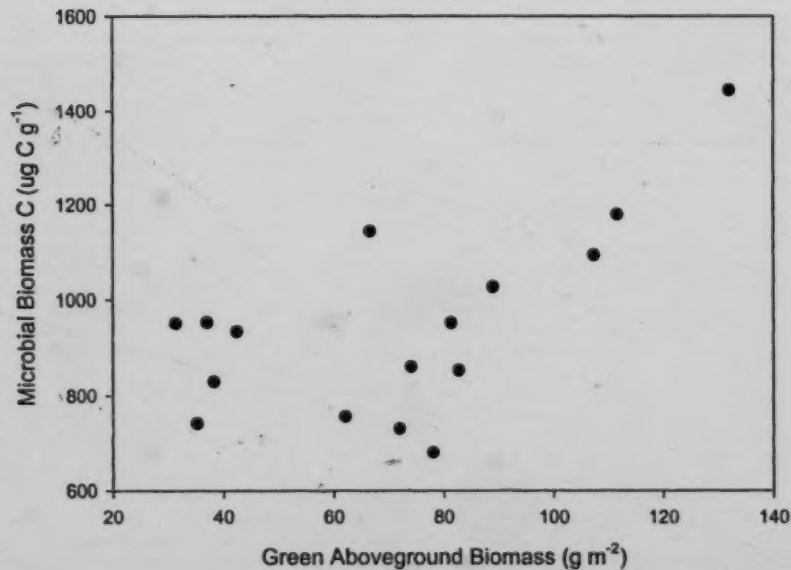


Fig 3.2. Relationship between microbial biomass ($\mu\text{g C g}^{-1}$) and standing aboveground biomass (g m^{-2}) at 9 sites in Jasper National Park, with means across 2 years, 2 seasons, and 2 soil types, for control and grazed plots ($r^2=0.44$; $P=0.001$).

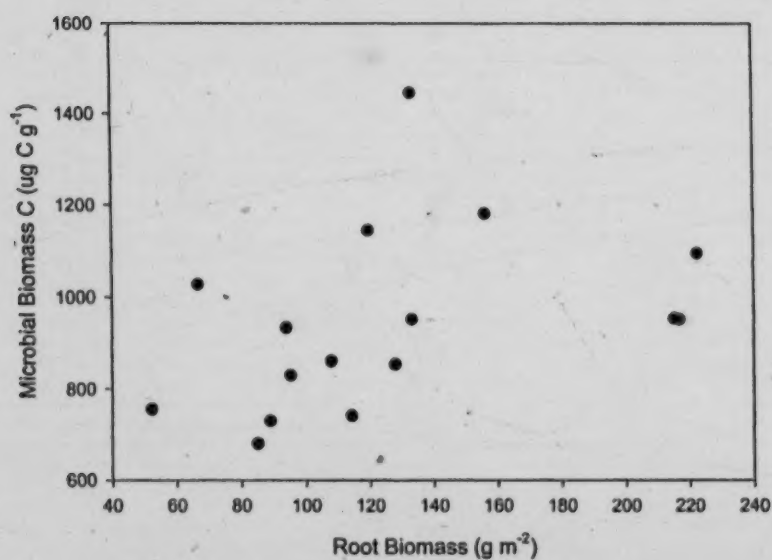


Fig 3.3. Relationship between microbial biomass ($\mu\text{g C g}^{-1}$) and root biomass (g m^{-2}) at 9 sites in Jasper National Park, with means across 2 years, 2 seasons, and 2 soil types for control and grazed plots ($r^2=0.23$; $P=0.095$).

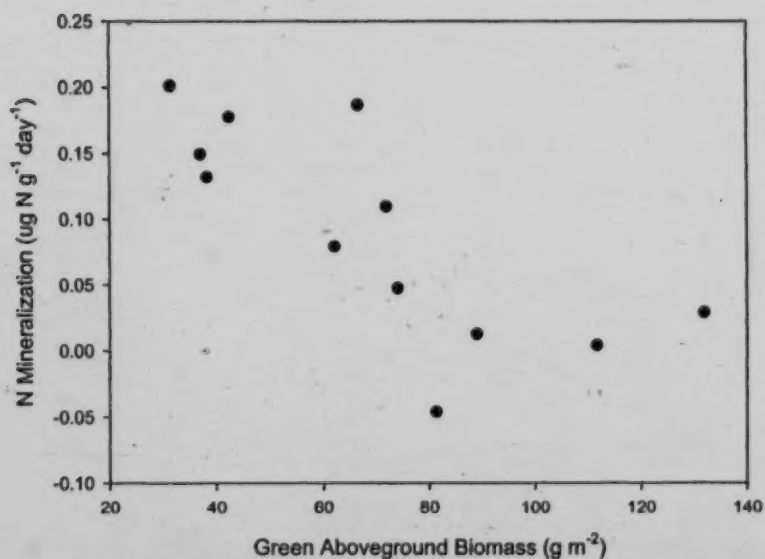


Fig 3.4. Relationship between net N mineralization rate ($\mu\text{g N g}^{-1} \text{ day}^{-1}$) and standing aboveground biomass (g m^{-2}) at 9 sites in Jasper National Park, with means across 2 years, 2 seasons and 2 soil types, for control and grazed plots ($r^2=-0.46$; $P=0.011$).

Table 3.2. Mean and standard deviation of total standing biomass (g m^{-2}), root biomass (g m^{-2}), root length (cm) and root to aboveground biomass ratio in plots (0.25m^2) on sandy and loamy soils subject to winter (W), winter/spring (W/Sp), year-round (YR) and natural grazing sampled in spring and fall 2001 in grasslands in Jasper National Park. P values are given for differences between soil types (S), defoliation treatment (T), and soil x defoliation (S*T) interactions. * indicates a significant difference between spring and fall values within soil type and defoliation treatment, $P \leq 0.10$.

	Sandy Soil										Loamy Soil										P-Value		
	Control					W/Sp					Year-round					Grazed							
	Winter		W/Sp		Year-round		Grazed		Control		Winter		W/Sp		Year-round		Grazed		S	T	S*T		
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd					
Green biomass	51	36	49	32	49	37	--	23	12	70	34	73	35	59	30	--	--	54	34	0.09	0.52	0.94	
May	63	20	80	44	72	34	64	40	52*	93	55	93	69	91	56	75	40	79	40	0.21	0.91	0.99	
August	85	25	102	76	80	23	--	--	114	102	223	185	205	127	143	74	--	128	57	0.05	0.81	0.71	
Root biomass	67	25	93	24	91	37	90	27	108	52	133	69	148	39	129	79	136	27	156	104	0.01	0.84	0.99
June	438	88	428	157	506	49	--	--	416	102	1086	649	1035	294	835	406	--	853	513	0.00	0.92	0.85	
October	334	148	527	200	402	182	578	336	506	230	772	270	696	315	791	246	658	336	726	160	0.00	0.98	0.59
Root:AB ratio	3.02	3.23	2.02	0.32	2.28	1.26	--	--	5.23	3.83	3.50	3.40	3.09	1.55	2.51	1.27	--	2.58	0.86	0.79	0.54	0.39	
June: May	1.14	0.20	1.65	1.47	1.59	1.24	1.78	2.03	2.39	0.92	2.20	1.54	2.39	1.31	1.81	1.20	2.65	2.03	2.94	0.22	0.78	0.99	
Oct: August	4/4 ¹		3/3		6/3		3		4/4 ¹		5/5		5/5		5/5		5/5		5/5				

¹ Plots at Edna were sampled for control and natural grazing only, except for standing AB and root:AB ratio, which were not sampled in 2001.

Table 3.3. Mean and standard deviation of microbial biomass C (ug C g⁻¹), microbial biomass N (ug N g⁻¹), microbial biomass C:N ratio, net N mineralization rate (ug N g⁻¹ day⁻¹), mineral N (ug N g⁻¹), soil moisture (%), soil moisture (%) in plots on sandy and loamy soils subject to winter (W), winter/spring (W/Sp), year-round (YR) and natural grazing sampled in spring and fall 2001 in grasslands in Jasper National Park. *P* values are given for differences between soil types (S), defoliation treatments (T), and soil x defoliation (S*T) interactions. * indicates a significant difference between spring and fall values across sites within soil and treatment types, *P* < 0.10.

	Sandy Soil						Loamy Soil						P-Value						
	Control		Winter		W/S ^a		Control		Winter		W/S ^a		Year-round		Grazed		S	T	S-T
	x	sd	x	sd	x	sd	x	sd	x	sd	x	sd	x	sd	x	sd			
Microbial C	680	288	790	289	780	275	1095	380	1174	461	1134	400	854	372	--	--	0.83	0.77	0.85
June	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
October	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Microbial N	107	34	84	21	109	36	135	37	164	55	178	60	189	57	--	--	0.00	0.75	0.49
June	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
October	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Microbial C:N	6.36	2.18	9.34	2.46	7.20	0.85	8.01	1.73	7.18	1.90	6.41	0.94	4.85	2.26	--	--	0.11	0.66	0.12
June	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
October	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Net N mineralization rate	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
May-June	--	--	--	--	--	--	--	--	--	--	--	--	-0.06	0.13	0.00	0.19	--	--	0.87
Sept-Oct	0.01	0.05	-0.04	0.09	0.03	0.02	0.03	0.06	-0.04	0.09	0.01	0.11	--	--	--	--	0.40	0.79	--
NH ₄ ⁺	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
May and June	--	--	--	--	--	--	--	--	--	--	--	--	3.76	2.09	3.82	2.36	0.00	0.96	0.99
Sept and Oct	1.63	0.94	2.02	1.62	1.66	1.14	4.14	1.97	4.44	2.30	3.36	1.64	--	--	--	--	--	--	--
NO ₃ ⁻	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
May and June	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sept and Oct	5.70	2.00	6.07	1.93	5.72	2.40	2.92	1.39	3.94	2.48	3.74	2.69	3.87	2.44	4.74	1.79	0.01	0.94	0.94
Mineral N	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
May and June	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sept and Oct	7.13	2.96	7.59	4.03	6.90	3.35	6.63	3.02	8.93	5.33	7.02	5.42	8.50	5.59	8.52	6.29	0.54	0.97	0.98
Soil moisture	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
May and June	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sept and Oct	7.2	2.5	5.8	2.1	6.0	2.4	15.7	4.7	15.3	3.0	14.0	4.2	15.2	4.5	14.1	5.1	0.00	0.94	0.98
Spring/Fall	4/4'	--	3/3	--	6/3	--	5/5	--	5/5	--	5/5	--	5/5	--	5/5	--	--	--	--

^a Plots at Edna were sampled for control and natural grazing only.

Table 3.4. Mean and standard deviation of green biomass (g m^{-2}), % cover of total vegetation, standing dead, and litter, root biomass (g m^{-2}), root length (cm) and root to aboveground biomass ratio in plots (2.5m^2) on sandy and loamy soils subject to winter (W), winter/spring (W/Sp), year-round (YR) and natural grazing sampled in spring and fall 2002 in grasslands in Jasper National Park. P values are given for differences between soil types (S), defoliation treatments (T), and soil x defoliation (S*T) interactions. * indicates a significant difference between spring and fall values within soil type and defoliation treatment, $P \leq 0.10$.

	Sandy Soil										Loamy Soil										P-Value				
	Control					Winter					W/Sp					Year-round								Grazed	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	W/Sp	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	S	T	S*T		
Green biomass																									
May	28	8	35	4	29	5	--	--	25	6	21	10	20	7	24	9	--	--	24	10	0.01	0.79	0.33		
September	44*	7	53	24	51	24	51*	8	57*	23	61*	19	58*	26	39	12	47*	22	47*	22	0.44	0.41	0.90		
Total Production																									
August	82	32	127	73	146	63	158	39	139	63	158	65	148	56	180	78	144.2	81	144.2	81	0.00	0.88	0.75		
% Total Veg																									
Cover																									
May	40	19	42	14	34	14	--	--	26	14	43	24	44	12	37	13	--	--	33	17	0.54	0.37	0.99		
September	42	23	43	17	35	20	40	23	30	11	52	22	44	14	33	12	41	22	35	20	0.63	0.45	0.98		
% Standing Dead																									
Cover																									
May	14	9	13	7	8	4	--	--	4	2	18	10	11	6	12	7	--	--	10	13	0.31	0.14	0.84		
September	20*	20	16*	8	6*	4	13*	5	6*	5	30*	18	16*	5	8*	2	19*	18	10*	12	0.28	0.05	0.95		
% Litter																									
May	25	13	24	11	29	1	--	--	17	9.5	40	25	43.6	26	30	15	--	--	16	12	0.17	0.17	0.57		
September	29*	14	37*	6	41*	15	51*	6	30*	14	36*	11	31*	13	25*	10	18*	18	18*	18	0.20	0.00	0.14		
Root biomass																									
June	94	48	70	7	97	31	--	--	95	60	217	175	199	186	178	135	215	199	217	176	0.01	0.98	0.97		
October	52	29	52	20	60	27	86	71	89	22	133	64	142	89	101	44	129	71	120	54	0.00	0.88	0.75		
Root length																									
June	454	102	389	15	510	104	--	--	399	75	922	320	1093	462	828	339	--	--	884	372	0.00	0.92	0.54		
October	296	150	304	148	360	97	413	574	342	60	1010	531	1173	624	933	430	998	574	931	606	0.00	0.99	0.96		
Root:AB ratio																									
June: May	3.45	1.80	2.01	0.08	3.36	0.85	--	--	4.10	2.86	16.0	22.1	12.2	14.5	9.47	10.4			8.06	4.38	0.02	0.88	0.82		
Oct: Sept	1.21*	0.66	1.14	0.76	1.31*	0.89	2.15	1.11	1.80	0.56	2.39	0.75	2.18	0.92	1.89*	0.61	3.08	1.11	2.65*	1.03	0.00	0.11	0.96		
Spring/Fall	4/4 ²		3/3		3/6		3	4/4 ²	5/5		5/5		5/5		5/5		5		5/5						

Plots at Edna were sampled for control and natural grazing only

² Plots at Edna were sampled for control and natural grazing only.

Table 3.5. Mean and standard deviation of microbial biomass C (ug C g⁻¹), microbial biomass N (ug N g⁻¹), microbial biomass C:N ratio, net N mineralization rate (ug N g⁻¹ day⁻¹), mineral N (ug N g⁻¹), soil moisture (%) in plots on sandy and loamy soils subject to winter (W), winter/spring (W/Sp), Year-round (YR) and natural grazing sampled in spring (May-June) and fall (September - October) 2002 in grasslands in Jasper National Park. P values are given for differences between soil types (S), defoliation treatments (T), and soil x defoliation (S*T) interactions. * indicates a significant difference between spring and fall values across sites within soil and treatment types, $P \leq 0.10$.

	Sandy Soil										Loamy Soil										P-Value		
	Control		Winter		W/Sp		Year-round		Grazed		Control		Winter		W/Sp		Year-round		Grazed				
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	S	T	S*T
Microbial C	934	168	943	160	951	214	--	--	830	260	951	252	826	173	1064	375	--	--	954	184	0.69	0.66	0.76
June	756	164	773	199	882	286	769	342	730	243	952	315	971	199	900	72	764	342	1144*	99	0.83	0.66	0.36
October	138	27	141	24	139	30	--	--	119	38	142	42	126	32	168	58	--	--	153	35	0.35	0.67	0.58
Microbial N	115	20	115	30	127	38	117	31	113	36	146	44	154	33	146	27	140	31	184	18	0.00	0.69	0.47
June	6.78	0.55	6.73	0.47	6.87	0.39	--	--	6.97	0.14	6.76	0.33	6.62	0.34	6.42	0.69	--	--	6.28	0.42	0.06	0.91	0.45
October	6.55	0.27	6.71	0.12	6.87	0.36	6.57	2.09	6.40*	0.25	6.50	0.29	6.34	0.27	6.27	0.73	5.46	2.09	6.23	0.18	0.09	0.66	0.72
Microbial C:N																							
Net N mineralization rate	0.17	0.32	0.18	0.17	0.14	0.12	--	--	0.13	0.10	0.20	0.18	0.20	0.32	0.15	0.48	--	--	0.22	0.14	0.76	0.99	0.93
May-June	0.08	0.11	0.04	0.07	0.07*	0.10	0.04	0.14	0.11	0.18	-0.05	0.15	0.04	0.08	-0.04	0.10	-0.01	0.14	0.19	0.35	0.44	0.42	0.72
Sept-Oct	3.64	4.06	4.47	4.05	4.23	3.39	--	--	3.30	2.30	9.21	5.29	12.5	7.37	11.3	5.63	--	--	7.11	3.23	0.89	0.50	0.81
NH ₄ ⁺	2.88	1.78	3.75	2.32	2.75	1.66	3.23	2.69	3.26	3.06	5.36	3.21	5.41	3.97	4.77	3.04	5.04	3.54	4.54	3.35	0.67	0.99	0.99
May and June																							
Sept and Oct	9.85	3.12	10.8	2.89	10.67	4.60	--	--	11.27	5.20	6.36	5.32	7.08	6.38	5.06	3.44	--	--	8.78	5.47	0.82	0.72	0.87
NO ₃ ⁻	7.72	3.50	7.08	3.39	7.18	3.72	6.63	3.27	8.38	1.81	7.24	3.65	8.69	5.84	7.49	4.21	7.47	4.50	11.4	4.78	0.43	0.65	0.93
May and June																							
Sept and Oct	12.8	7.1	14.7	6.9	14.0	8.7	--	--	13.7	7.1	15.6	6.7	19.6	12.4	16.3	7.0	--	--	15.7	5.8	0.26	0.88	0.98
Mineral N	10.6	5.2	10.8	5.6	9.9	5.1	9.9	7.8	11.6	3.6	12.6	6.6	14.1	9.7	12.3	7.1	12.5	7.8	15.9	7.9	0.20	0.93	0.99
May and June																							
Sept and Oct	9.8	2.6	10.8	1.6	11.0	2.0	--	--	9.5	5.0	26.8	8.8	26.0	7.5	28.3	7.5	--	--	27.1	6.0	0.00	0.94	0.98
Soil moisture	10.8	2.6	11.4	1.7	11.5	1.6	11.5	6.5	11.1	3.0	19.6	5.5	20.3	8.0	19.7	6.9	19.4	6.5	18.4	4.8	0.00	0.99	0.99
May and June																							
Sept and Oct	4/4 ¹	3/3	6/3	3	4/4 ¹	5/5	10/5	5	5/5	5/5	5/5	5/5	5/5	5/5	10/5	5	5	5	5/5	5/5			
Spring/Fall																							

Plots at Edna were sampled for control and natural grazing only.

¹ Plots at Edna were sampled for control and natural grazing only.

microbial C/N ratio was greater ($P=0.09$) in control plots (6.53 ± 0.28) than grazed (6.31 ± 0.22).

Across defoliation treatments, however, I found differences related to year, season, and particularly soil type. Standing green biomass was 17% greater in 2001 than 2002 ($P<0.001$), and was generally higher on loamy soils than sandy soils except in spring of 2002 when standing biomass was considerably lower than at other sampling periods (Table 3.6). Total vegetation cover, including green and dead standing material, was 34% higher in loamy soils than sandy ($P<0.10$), but was unaffected by season (Table 3.6). In contrast, root biomass and length were similar between years, but root biomass averaged 85% greater, and root length 109% greater on loamy soils than sandy (Table 3.6). As a result, the ratio of root/total standing biomass was 256% higher in spring than fall in 2002 while the ratio for loamy soils in 2002 was greater than those for sandy 2002, sandy and loamy 2001, primarily due to high root biomass and low standing aboveground biomass values at Moberly in spring 2002.

Differences in microbial biomass C and N were compared only for the spring sampling period, due to missing data for fall 2001. In spring, microbial biomass C was 25% higher in loamy soils than sandy soils, and microbial N was 72% higher in loamy soils than sandy soils (Table 3.7). Nevertheless, ratio of microbial C/N was 11% higher in sandy soils than loamy soils in spring, across years ($P=0.05$).

Soil N and N mineralization could only be analyzed in the fall because of missing spring 2001 data. Neither year nor soil type had any effect on net N mineralization rates (Table 3.7). Total mineral N, however, was 62% higher in 2002 than 2001 ($P<0.01$), while loamy soils had 18% greater mineral N than sandy soils ($P<0.10$). Similarly, NO_3^-

was 68% higher in 2002 than 2001 ($P < 0.01$), but sandy soils had 26% greater NO_3^- than loamy soils ($P < 0.10$). NH_4^+ was 88% greater in 2002 than 2001 ($P < 0.10$) and 30% greater in loamy soils compared to sandy ($P < 0.01$). Compared to loamy soils, sandy soils lost 209% more mineral N through leaching ($P < 0.001$), with 197% greater NO_3^- loss and 267% greater NH_4^+ loss in sandy soils than loamy soils ($P < 0.001$). Finally, soil moisture was 9.4% lower in sandy soils than loamy soils, and was similar between years ($P < 0.001$), while soil moisture at 5-15 cm was 81% greater in loamy soils than sandy soils ($P < 0.001$).

Discussion

In my defoliation experiment, I found few differences in aboveground plant biomass and no differences in soil characteristics in the montane grasslands among seasonal defoliation treatments after two years of clipping. Vegetation in clipped plots recouped during the growing season such that there was no difference in green biomass or total production among defoliation treatments, but both standing dead plant cover and litter cover were reduced by grazing in spring and fall. Similar reductions in standing plant material have been reported for grazed grasslands in Yellowstone (Coughenour 1991), North Dakota (Biondini and Manske 1996), and Wind Cave National Park (Detling 1998).

Unlike studies in Wind Cave (Holland and Detling 1990) and southern Alberta (Willms *et al.* 1990), and contrary to my hypotheses, neither root biomass nor microbial biomass or activity were affected by defoliation treatments. Clipping may not have elicited the expected responses for several reasons. First, my clipping treatments may not have been severe enough to produce a response from the vegetation. I clipped vegetation

Table 3.6. Mean and standard deviation of green biomass (g m^{-2}), % cover of total vegetation, standing dead, and litter, root biomass (g m^{-2}), root length (cm), root to aboveground biomass ratio in plots (2.5 m^2) on sandy and loamy soils in Jasper National Park, sampled in spring and fall 2001 and 2002 (see Tables 3.1 – 3.4 for exact sampling months). *P* values are given for difference between year, season, soils, and year x season (*Y*Se*) interactions, year x soil (*Y*So*) interactions, season x soil (*Se*So*) interactions, and year x season x soil (*Y*Se*So*) interactions. Superscript letters represent differences at the *P* value stated on right of chart.

	2001						2002						P-Value					
	Spring			Fall			Spring			Fall								
	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Year	Season	Soil	Y*Se	Y*So	Se*So
Green biomass $\bar{x}$	65.8 ^a	98.2 ^b	94.0 ^b	122.2 ^c	45.5 ^a	34.5 ^a	69.0 ^{ab}	74.3 ^{ab}	0.00	0.00	0.02	0.92	0.06	0.91	0.76			
s.d.	44.5	48.4	40.4	69.8	9.2	12.7	21.2	29.6										
% Total Veg Cover $\bar{x}$	--	--	--	--	28.0 ^a	31.3 ^a	38.7 ^{ab}	40.9 ^a	--	0.09	0.13	--	--	0.99	--			
s.d.	--	--	--	--	20.0	21.7	18.3	18.3										
% Standing Dead Cover $\bar{x}$	--	--	--	--	6.9 ^a	10.1 ^b	11.6 ^b	16.5 ^c	--	0.11	0.06	--	--	0.95	--			
s.d.	--	--	--	--	6.1	9.5	12.8	14.1										
% Litter Cover $\bar{x}$	--	--	--	--	24.0 ^a	32.8 ^a	33.5 ^a	27.8 ^a	--	0.84	0.11	--	--	0.18	--			
s.d.	--	--	--	--	10.3	20.3	19.3	13.7										
Root biomass $\bar{x}$	95.5 ^a	174.7 ^{abc}	89.4 ^a	140.6 ^b	91.2 ^a	197.6 ^c	68.1 ^a	125.0 ^{ab}	0.86	0.13	0.00	0.67	0.75	0.34	0.91			
s.d.	58.0	119.2	34.1	62.4	39.1	157.0	29.7	62.0										
Root length $\bar{x}$	447 ^a	952 ^c	484 ^a	729 ^b	448 ^a	912 ^c	342 ^a	1009 ^c	0.91	0.69	0.00	0.73	0.24	0.97	0.13			
s.d.	98	458	215	253	100	359	125	517										
Root:Standing biomass $\bar{x}$	3.1 ^b	2.9 ^a	1.7 ^a	2.4 ^a	2.9 ^a	11.0 ^b	1.5 ^a	2.4 ^a	0.14	0.01	0.01	0.11	0.08	0.25	0.10			
s.d.	2.6	1.9	1.0	1.7	1.0	13.0	0.8	0.9										

Table 3.7. Mean and standard deviation of microbial C ($\mu\text{g C g}^{-1}$), microbial N ($\mu\text{g N g}^{-1}$), net N mineralization ($\mu\text{g N g}^{-1} \text{ day}^{-1}$), mineral N ($\mu\text{g N g}^{-1}$), % soil moisture, and leached N ($\mu\text{g N g}^{-1}$) in plots (2.5m^2) on sandy and loamy soils in Jasper National Park, sampled in spring and fall 2001 and 2002 (see Tables 3.1 – 3.4 for exact sampling months). *P*-values are given for difference between year, season, soils, and year x season (*Y*Se*) interactions, year x soil (*Y*So*) interactions, season x soil (*Se*So*) interactions, and year x season x soil (*Y*Se*So*) interactions. Superscript letters represent differences at the *P* value stated on right of chart.

	2001						2002						<i>P</i> -Values		
	Spring			Fall			Spring			Fall			Year	Season	Soil
	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy	Loamy			
Microbial C $\bar{x}$	748 ^a	1064 ^b	—	—	—	—	949 ^{ab}	972 ^b	789 ^a	946 ^b	—	—	0.73	—	0.86
s.d.	247	393	—	—	—	—	185	287	207	247	—	—	0.11	—	—
Microbial N $\bar{x}$	96.6 ^a	166.6 ^b	—	—	—	—	139.0 ^b	151.1 ^b	118.3 ^a	153.7 ^b	—	—	0.40	—	0.82
s.d.	26.7	53.0	—	—	—	—	27.8	47.0	28.6	33.2	—	—	0.00	—	—
Microbial C:N $\bar{x}$	8.1 ^b	6.6 ^a	—	—	—	—	6.8 ^{ab}	6.5 ^a	6.6 ^a	6.2 ^a	—	—	0.29	—	0.65
s.d.	3.1	2.0	—	—	—	—	0.4	0.5	0.3	1.0	—	—	0.23	—	0.43
Net N mineralization $\bar{x}$	—	—	—	—	—	—	0.015 ^{ab}	0.138 ^a	0.089 ^b	0.027 ^{ab}	—	—	0.00	—	0.86
s.d.	—	—	—	—	—	—	0.083	0.119	0.098	0.197	—	—	0.67	—	—
Total mineral N $\bar{x}$	—	—	—	—	—	—	7.17 ^a	16.71 ^d	10.73 ^b	13.47 ^{bc}	—	—	0.00	—	0.67
s.d.	—	—	—	—	—	—	3.29	7.71	4.66	7.35	—	—	0.00	—	0.67
NO ₃ ⁻ $\bar{x}$	—	—	—	—	—	—	7.17 ^a	16.71 ^d	10.73 ^b	13.47 ^{bc}	—	—	0.06	—	0.94
s.d.	—	—	—	—	—	—	3.29	7.71	4.66	7.35	—	—	0.38	—	0.33
NH ₄ ⁺ $\bar{x}$	—	—	—	—	—	—	1.78 ^a	10.29 ^d	3.29 ^b	5.02 ^c	—	—	0.00	—	—
s.d.	—	—	—	—	—	—	1.10	5.58	2.20	3.16	—	—	0.00	—	—
Soil moisture $\bar{x}$	—	—	—	—	—	—	8.6 ^a	27.3 ^c	11.5 ^a	19.5 ^b	—	—	0.00	—	—
s.d.	—	—	—	—	—	—	3.4	7.1	1.9	5.9	—	—	0.00	—	—
Leached mineral N $\bar{x}$	—	—	—	—	—	—	30.3 ^b	9.8 ^a	—	—	—	—	0.00	—	—
s.d.	—	—	—	—	—	—	21.2	6.8	—	—	—	—	0.00	—	—
Leached NO ₃ ⁻ $\bar{x}$	—	—	—	—	—	—	24.6 ^b	8.3 ^a	—	—	—	—	0.00	—	—
s.d.	—	—	—	—	—	—	16.9	5.2	—	—	—	—	0.00	—	—
Leached NH ₄ ⁺ $\bar{x}$	—	—	—	—	—	—	5.7 ^a	1.6 ^a	—	—	—	—	0.00	—	—
s.d.	—	—	—	—	—	—	6.0	2.2	—	—	—	—	0.00	—	—
n	15	25	15	25	15	25	15	25	15	25	15	25	—	—	—

to a height of 5-10 cm, which is less severe than the 4-6 cm height that many laboratory defoliation experiments imposed (Detling *et al.* 1979, Stanton 1983, Guitian and Bardgett 2000). Further, the frequency of my clipping treatments may have been insufficient to produce a response. For example, Guitian and Bardgett (2000) found that it took a clipping intensity of once to every 2 weeks for graminoid root biomass to decrease by 25%. My clipping, however, resulted in removal of 36.2% and 20.2% of available biomass in spring and summer, respectively, similar to the amounts removed by herbivores in spring ($31.8\% \pm 6.3\%$) and summer ($23.5\% \pm 5.6\%$). Thus, although I removed less biomass than in many grazing studies (Willms *et al.* 1990, Frank and McNaughton 1992, Hart *et al.* 1993, Biondini and Manske 1996), I mimicked natural grazing levels in Jasper.

Although my clipping treatments closely mimicked natural grazing levels in Jasper, my sampling regime may have prevented me from detecting a response. For example, in a recent greenhouse study, Hamilton and Frank (2001) clipped *Poa pratensis* to 6 cm in height, destructively harvesting at 24 hours and 7 days. They observed a 2-fold increase in soluble soil C just 24 hours following defoliation, as well as elevated net N mineralization, and 60% and 33% increases in NH_4^+ and NO_3^- , respectively (Hamilton and Frank 2001). It was hypothesized that defoliation promoted a rapid, transient flux of C and N to the rhizosphere from root mortality or root exudation, with assimilation into the microbial population, resulting in elevated net N mineralization rates, soil inorganic N pools, plant uptake, and leaf N (Hamilton and Frank 2001). After 7 days, however, there were no differences between clipped and control plants, suggesting that my sampling regime may not have detected the response by sampling >28 days after defoliation.

Further, because Jasper's soils tend to be very shallow, (Stringer 1969), I could only sample to a depth of 5 cm, and may have missed responses to clipping in the lower soil depths. For example, in most grassland systems, the majority of the microbial biomass, root biomass, and net N mineralization occurs within the top 15 cm of soil (Willms *et al.* 1990, Raison *et al.* 1987, Murphy *et al.* 1998). For example, in two Australian soils, both sandy-loamy, 55% of microbial biomass was found in the top 10 cm of soil, and >50% of that was in the top 2.5 cm (Murphy *et al.* 1998). Further, Raison *et al.* (1987) found that between 29 – 43% of net N mineralization occurred in the top 5 cm of sandy podzolic soil, while Paul *et al.* (2001) found that in clay loam soils, 56% of the net N mineralization in the top 15 cm of soil occurred in the 0-5 cm layers. Willms *et al.* (1990) reported that in the mixed prairie, >50% of root biomass occurred within the top 15 cm of soil. In 2002, I measured root biomass in 0-5 cm and 5-15 cm depths at Devona Hill and Warden's Office, and found that 74% of the root biomass in the 15 cm core occurred in the 0 – 5 cm layer. Similarly, using a 0.25 mm mesh sieve, Greenwood and Hutchison (1998) found that 52% of roots occurred within the top 5 cm of prairie soil. The root samples in this study were put through a 4-mm sieve, which is large compared to most studies (Barker *et al.* 1988, Greenwood and Hutchison 1998, McNaughton *et al.* 1998), and may have resulted in loss of finer roots. For example, using a mini-rhizotron, (Gill *et al.* 2002) found that the majority of roots in the short-grass steppe had a diameter <0.3 mm. However, in some preliminary work for this study in 2001, I found that roots between 1- 4 mm in diameter comprised only $25\% \pm 32\%$ (mean $\pm$ SD) of the biomass, indicating that a 4 mm sieve collected the majority of the roots. Thus, although my 5 cm soil cores and 4 mm sieve size may have resulted in some

sample loss, these losses would be similar among the treatments and should not affect relative values.

Alternatively, Jasper's cold, dry climate (Rhemtulla 1999) may result in slow nutrient cycling rates (Hassink *et al.* 1993), with low overall production and available C and N, leading to few detectable treatment differences. Montane grasslands in Canada receive an average 515 mm of precipitation annually, ranging from 308 mm to 1279 mm (Willoughby 1997), compared with the average 385 mm received annually by Jasper's winter ranges (Environment Canada 2002). In fact, grasslands in the Jasper Lake and Snake Indian River areas of Jasper, including Devona Hill, Edna, and Windy Point, receive <380 mm precipitation annually, the least of all areas within the Canadian Rocky Mountain Parks (Janz and Storr 1977). However, Tracy and Frank (1998) found differences in net N mineralization in Yellowstone's northern range, which also received <380 mm of annual precipitation so precipitation alone may not explain the differences between Jasper and Yellowstone. Likewise, percent soil moisture in spring was also similar in Yellowstone ($11.8\% \pm 3.3\%$; Coughenour 1991) and Jasper ($10.3\% \pm 2.5\%$). However, in Yellowstone, the highest growing season precipitation is received in May and June, according to 30-year monthly precipitation averages (USGS Data), while in Jasper peak precipitation occurs in July and August, resulting in relatively low moisture availability during the growing season. Thus, production and nutrient cycling may be lower in Jasper due to both total amount and timing of precipitation, preventing me from detecting any small treatment differences with my sampling regime.

Although I detected few responses, soil texture had an effect on root biomass, microbial biomass, and net N mineralization. Total production was similar on loamy and

sandy soils, although root biomass was lower in sandy soils, at least partially because plants in sandy soils were allocating 104% more C aboveground than to roots, according to the root/aboveground biomass ratio. Thus, in contrast to those on loamy soils, plants at sandy sites may be maintaining aboveground biomass at the expense of root biomass, which may compromise the recovery rate of grazed plants at sandy sites. Not only did loamy sites have greater root biomass, but microbial biomass and mineral N were also higher. Microbial biomass is directly related to organic C (Ruess and McNaughton 1987) and percent clay in soil (Hassink *et al.* 1993), both of which increase with production (Milchunas and Lauenroth 1993). Root-derived C, from root turnover and exudates, provides important substrate for microbial biomass (Merckx *et al.* 1985; Holland & Detling 1990). Hassink *et al.* (1993) suggested that lower microbial biomass in sandy soils was due to increased predation by bacterivorous nematodes. Because of relatively large pore diameters (Rutherford & Juma 1992; Sakamoto & Hodono 2000), microbes in sandy soils cannot escape predation. Fine-textured soils have both greater physical and chemical protection (Hassink *et al.* 1997), and so microbial biomass may be greater on loamy soils not only because of greater available C in loamy soils, but because of a higher capacity to protect microbes. In either case, loamy soils may have larger active soil C pools due to greater microbial biomass, and are thus more productive than sandy soils.

Although I saw much higher mineral N in loamy soils, net N mineralization rates were often just as high or higher in sandy soils than loamy soils, and NO_3^- was 26% greater in sandy soils. In contrast, NH_4^+ was lower in sandy soils, possibly due to lower cation exchange capacity in sandy soils, which have lower clay content than loamy soils

(Hassink et al. 1997). Thus, sandy soils have lower N content due to larger pore diameters leading to greater N leaching, and because of lower cation exchange capacity. Plants have been found to preferentially take up NO_3^- because it is more mobile than NH_4^+ and diffuses more rapidly through soil solutions to be taken up by plant roots (Frank and Evans 1997). Increased NO_3^- availability at sandy sites implies that those plants do not need to invest as much C to roots as plants on loamy sites, supporting the lower root/AB ratio observed with plants on sandy soils. Mineral N, however, especially NO_3^- , was subject to high degrees of leaching in sandy soils, suggesting that mineral N is limiting in sandy grasslands, perhaps inhibiting production.

Effects of soil type and year far outweigh the effects of grazing, and I could not detect an interaction among soil type and grazing in plant and soil processes. Tracy and Frank (1998) found that soil texture had more of an effect on microbial biomass than grazing, and grazing had a greater effect on net N mineralization, but that there was no interactive effect of grazing with soil type. Similarly, Frank and Groffman (1998) found that plant production across the landscape had as great an influence on net N mineralization as grazing. In my study, any effect that defoliation had in stimulating carbon turnover and nutrient cycling could not be detected relative to the effects of soils alone. In Yellowstone, there was a difference in total plant biomass of $\sim 1200 \text{ g m}^{-2}$ in summer between the most xeric, sandy sites and the most mesic, loamy sites (Tracy and Frank 1998), whereas in Jasper, the largest difference in green biomass between loamy and sandy sites was 56.2 g m^{-2} . If grazing effects on plant production increase with plant productivity (Milchunas and Lauenroth 1993) and if microbial populations also increase and are more active with plant productivity, this with reduced growing season

precipitation, may account for the differences observed in plant and soil responses reported for Yellowstone and Jasper National Park.

Conclusions

The results of this study indicate that soil texture had a greater effect than defoliation on C and N measures in these sandy and loamy grasslands. Although total production was unaffected by soil texture, sandy grasslands had lower root biomass, microbial biomass, mineral N, and higher leaching than loamy grasslands, suggesting lower overall active soil C and mineral N availability. However, grazing did not have a greater effect than at loamy sites, perhaps due to additional inputs of dung from herbivores may equalize the effects of grazing on sandy and loamy soils. Further, in the low elevation grasslands of Jasper National Park even long-term grazing at moderate defoliation produces no measureable effects on belowground processes and nutrient pools, but that even after 2 years, carbon flux to the ground in the form of litter may be reduced. Although dung inputs may replace litter inputs, they are likely more heterogeneous (Augustine and Frank 2001, Semmartin and Oosterheld 2001) and despite the more favourable C:N ratio, did not result in higher soil mineral N levels. These results imply that grasslands were able to sustain the present levels of grazing in winter at most sites, and that moderate increases in summer grazing may not have a large effect on belowground processes. Although total pellet group counts were 43.8% higher, and offtake consistently higher at sandy sites than loamy, winter pellet counts were 94% higher than pellet counts in summer, indicating that although most sites are used in summer, winter use is much more prevalent. Despite the removal of ~220 elk from the townsite in 1999 and 2000, my pellet group counts indicate that use is still greater close

to town, but that even this unnatural distribution pattern is not affecting belowground processes. Reduced litter inputs may eventually have implications for the sustainability of these grasslands, although dung inputs may compensate for loss of plant inputs.

Future Direction

The purposes of this study was to provide baseline data for managers in Jasper, so that research may move towards a more ecosystem-oriented approach, and study both aboveground and belowground processes. Measurements of C inputs to the soil system are important indicators of soil quality (Doran *et al.* 1994). In this study, I measured aboveground peak production and litter as aboveground nutrient sources, and root biomass and microbial biomass as indicators of readily available soil C. Macroorganic matter (MOM) is the lighter fraction of organic matter (Theng *et al.* 1989), is not physically protected, and therefore decomposes more quickly than other forms of organic matter (Yakovchenko *et al.* 1998). Thus, macroorganic matter may be a better indicator of changes to available soil C pools because the MOM fraction is more sensitive to changes in soil management than total soil organic matter (Janzen *et al.* 1992) or microbial biomass C and N (Biederbeck *et al.* 1994). Soil MOM may be separated from air-dried soil using a sieving/winnowing technique (Ellert and Johnson 1997), and the total C, N, and phosphorus (P) in the MOM fraction analysed. I did not measure macroorganic matter in this study because time and funding limitations.

Although I did not measure P, the alkaline soils of Jasper's grasslands may inhibit P solubility, resulting in low P availability (Pfeiffer 1948). Since P has a great effect on the ability of a plant to withstand adverse conditions, such as overgrazing (Pfeiffer 1948), it may be important to quantify how grazing affects P availability, and how P availability

affects the resilience of grazed vegetation. I therefore suggest that future researchers in Jasper build upon my data and explore further methods and nutrients. Specifically, I suggest that future researchers do the following:

- 1) Formally characterize the soils of each site, by digging soils pits and analysing soil texture and pH.
- 2) Examine the effects of grazing and soil texture on C, N, and P in soil macroorganic matter.
- 3) Continue to gather data on mineral N and net N mineralization.

Reference List

- Anderson, T-H., and K.H. Domsch. 1993. The metabolic quotient for CO₂ ($q\text{CO}_2$) as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils. *Soil Biol. Biochem.* 25(3): 393-395.
- Augustine, D.J., and D.A. Frank. 2001. Effects of migratory grazers on spatial heterogeneity of soil nitrogen properties in a grassland ecosystem. *Ecol.* 82(11): 3149-3162.
- Biederbeck, V.O., H.H. Janzen, C.A. Campbell, and R.P. Zentner. 1994. Labile soil organic matter as influenced by cropping practices in an arid environment. *Soil Biol. Biochem.* 26: 1647-1656.
- Biondini, M.E., and L. Manske. 1996. Grazing frequency and ecosystem processes in a northern mixed prairie, USA. *Ecol. Appl.* 6(1): 239-256.
- Biondini, M.E., B.D. Patton, and P.E. Nyren. 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecol. Appl.* 8: 469-479.
- Burke, I.C., C.M. Yonker, W.J. Parton, C.V. Cole, K. Flach, and D.S. Schimel. 1989. Texture, climate, and cultivation effects on soil organic matter content in U.S. grassland soils. *Soil Sci. Am. J.* 53: 800-805.
- Cardon, Z.G., A.D. Czaja, J.L. Funk, and P.L. Vitt. 2002. Periodic carbon flushing to roots of *Quercus rubra* saplings affects soil respiration and rhizosphere microbial biomass. *Oecologia*. 133: 215-223.
- Cid, M.S., J.K. Detling, A.D. Whicker, and M.A. Brizuela. 1991. Vegetational responses of a mixed-grass prairie site following exclusion of prairie dogs and bison. *J. Range Manage.* 44(2): 100-105.
- Coughenour, M.B. 1991. Biomass and nitrogen responses to grazing of upland steppe on Yellowstone's northern winter range. *J. Appl. Ecol.* 28: 71-82.
- Cowan, I.M. 1946. General report upon wildlife studies in the Rocky Mountain Parks. Canadian Wildlife Serv. Edmonton, Alberta.
- Detling, J.K., M.I. Dyer, and D.T. Winn. 1979. Net photosynthesis, root respiration, and regrowth of *Bouteloua gracilis* following simulated grazing. *Oecologia* 41: 127-134.
- Dormaar, J.F., B.W. Adams, and W.D. Willms. 1997. Impacts of rotational grazing on mixed prairie soils and vegetation. *J. Range Manage.* 50: 647-651.

- Engel, R.K., J.T. Nichols, J.L. Dodd, and J.E. Brummer. 1998. Root and shoot responses of sand bluestem to defoliation. *J. Range Manage.* 51: 42-46.
- Environment Canada 2002. http://www.msc-smc.ec.gc.ca/climate/products_services/cdcd iso c.cfm.
- Frank, D.A. 1998. Ungulate regulation of ecosystem processes in Yellowstone National Park: direct and feedback effects. *Wildl. Soc. Bull.* 26(3): 410-418.
- Frank, D.A., and R.D. Evans. 1997. Effects of native grazers on grassland N cycling in Yellowstone National Park. *Ecol.* 78: 2238-2248.
- Frank, D.A., and P.M. Groffman. 1998. Ungulate vs. landscape control of soil C and N processes in grasslands of Yellowstone National Park. *Ecol.* 79(7): 2229-2241.
- Frank, D.A., and S.J. McNaughton. 1992. The ecology of plants, large mammalian herbivores, and drought in Yellowstone National Park. *Ecol.* 73: 2043-2058.
- Frank, D.A., and S.J. McNaughton. 1993. Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. *Oecologia* 96: 157-161.
- Gold, W.G., and M.M. Caldwell. 1989. The effects of the spatial pattern of defoliation on regrowth of a tussock grass. *Oecologia* 80: 289-296.
- Greenwood, K.L., and K.J. Hutchison. 1998. Root characteristics of temperate pasture in New South Wales after grazing at three stocking rates for 30 years. *Grass and Forage Sci.* 53: 120-128.
- Groffman, P.M., P. Eagan, W.M. Sullivan, and J.L. Lemunyon. 1996. Grass species and soil type effects on microbial biomass and activity. *Plant and Soil.* 183: 61-67.
- Guitian, R., and R.D. Bardgett. 2000. Plant and soil microbial responses to defoliation in temperate semi-natural grassland. *Plant and Soil.* 220: 271-277.
- Hamilton, E.W., and D.A. Frank. 2001. Can plants stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. *Ecol.* 82(9): 2397-2402.
- Hart, R.H., S. Cloff, and P.S. Test. 1993. Grazing strategies, stocking rates and frequency and intensity of grazing on western wheatgrass and bluegrama. *J. Range Manage.* 46: 122-126.
- Hassink, J., L.A. Bouwman, K.B. Zwart, J. Bloem, and L. Brussard. 1993. Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils. *Geoderma.* 57: 105-128.

- Hassink, J., F.J. Matus, Chenu, C., and J.W. Dalenberg. 1997. Interactions between soil biota, soil organic matter, and soil structure. *In* Soil ecology in sustainable agricultural systems. Eds. Brussard, L. and R. Ferrara-Cerrato. Lewis Publishers, New York.
- Holechek, J.L., R.D. Pieper, and C.H. Herbel. 2001. Range management principles and practices. Prentice-Hall, Inc., New Jersey, USA.
- Holland, E.A., and J.K. Detling. 1990. Plant response to herbivory and belowground nitrogen cycling. *Ecol.* 71: 1040-1049.
- Holland, J.N., W.Cheng, and D.A. Crossley, Jr. 1996. Herbivore-induced changes in plant carbon allocation: assessment of below-ground C fluxes using carbon-14. *Oecologia* 107: 87-94.
- Jaeger, C.H., R.K. Monson, M.C. Fisk, and S.K. Schmidt. 1999. Seasonal partitioning of nitrogen by plants and soil microorganisms in an alpine ecosystem. *Ecol.* 80(6): 1883-1891.
- Janz, B., and D. Storr. 1977. The climate of the contiguous mountain parks: Banff, Jasper, Yoho, Kootenay. Parks Canada. Edmonton, Alberta.
- Janzen, H.H., C.A. Campbell, S.A. Brandt, G.P. Lafond, and L. Townley-Smith. 1992. Light organic matter in soils from long-term crop rotations. *Soil Sci. Soc. Am. J.* 56: 1799-1806.
- Jasmer, G.E., and J.L. Holechek. 1984. Determining grazing intensity on rangeland. *J. Soil Water Conserv.* January-February.
- Lane, D.R., D.P. Coffin, and W.K. Lauenroth. 1998. Effects of soil texture and precipitation on above-ground net primary production and vegetation structure across the Central Grassland region of the United States. *J. Veg. Sci.* 9: 239-250.
- Martens, R. 1995. Current methods for measuring microbial biomass C in soil: Potentials and limitations. *Biol Fertil Soils.* 19: 87-99.
- McNaughton, S.J. 1983. Serengeti grassland ecology: the role of composite environmental factors and contingency in community organization. *Ecol. Monogr.* 53: 291-320.
- Merckx, R., A. den Hartog, and J.A. van Veen. 1985. Turnover of root-derived material and related microbial biomass formation in soils of different texture. *Soil. Biol. Biochem.* 17(4): 565-569.

- Merrill, E.H., N.L. Stanton, and J.C. Hak. 1994. Responses of bluebunch wheatgrass, Idaho fescue, and nematodes to ungulated grazing in Yellowstone National Park. *Oikos* 69: 231-240.
- Mikola, J., G.M. Barker, and D.A. Wardle. 2000. Linking above-ground and below-ground effects in autotrophic microcosms: effects of shading and defoliation on plant and soil properties. *Oikos* 89: 577-587.
- Mikola, J., G.W. Yeates, G.M. Barker, D.A. Wardle, and K.I. Bonner. 2001. Effects of defoliation intensity on soil food-web properties in an experimental grassland community. *Oikos* 92: 333-343.
- Milchunas, D.G., and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecol. Monogr.* 63(4): 327-366.
- Monsi, M., Z. Uchijima, and T. Oikawa. 1973. Structure of foliage canopies and photosynthesis. *Annual Rev. Ecol. System.* 4: 301-327.
- Murphy, D.V., C.P. Sparling, I.R.P. Fillery. 1998. Stratification of microbial biomass C and N and gross N mineralisation with soil depth in two contrasting Western Australian agricultural soils. *Austr. J. Soil Res.* 36(1): 45-55.
- Noy-Meir, I. 1973. Desert ecosystems: environment and producers. *Ann. Rev. Ecol. System.* 4: 23-51.
- Oosterheld, M., and S.J. McNaughton. 1988. Intraspecific variation in the response of *Themeda triandra* to defoliation: the effect of time of recovery and growth rates and compensatory growth. *Oecologia* 77: 181-186.
- Paul, K., S. Black, and M. Conyers. 2001. Development of nitrogen mineralisation gradients through surface soil depth and their influence on surface soil pH. *Plant Soil* 234: 239-246.
- Pfeiffer, R.W. 1948. Some factors affecting the winter ranges of Jasper National Park. M.Sc. Thesis, University of British Columbia.
- Raison, R.J., M.J. Connell, and P.K. Khanna. 1987. Methodology for studying fluxes of soil mineral-N *in situ*. *Soil Biol. Biochem.* 19(5): 521-530.
- Rhemtulla, J.M. 1999. Eighty years of change: the montane vegetation of Jasper National Park. M.Sc. thesis, University of Alberta.
- Robertson, G.P., D.C. Coleman, C.S. Bledsoe, and P. Sollins. 1999. Standard Soil Methods for Long-term ecological research. LTER. Oxford University Press, England.

- Ruess, R.W., and S.J. McNaughton. 1987. Grazing and dynamics of nutrient and energy regulated microbial processes in the Serengeti grasslands. *Oikos* 49: 101-110.
- Rutherford, P.M. and N.G. Juma. 1992. Influence of texture on habitable pore space and bacterial-protozoan populations in soil. *Biol. Fert. Soils* 12: 221-227.
- Sakamoto, K. and N. Hodono. 2000. Turnover time of microbial biomass carbon in Japanese upland soils with different textures. *Soil Sci. Plant Nutr.* 46(2): 483-490.
- Semmartin, M., and M. Oesterheld. 2001. Effects of grazing pattern and nitrogen availability on primary production. *Oecologia*. 126: 225-230.
- Stanton, N.L. 1983. The effect of clipping and phytophagous nematodes on net primary production of blue grama, *Bouteloua gracilis*. *Oikos*. 40: 249-257.
- Stringer, P.W. 1969. An ecological study of grasslands at low elevations in Banff, Jasper, and Waterton Lakes National Parks. Ph.D. Thesis, University of Alberta.
- Theng, B.K.G., K.R. Tate, and P. Sollins. 1989. Constituents of organic matter in temperate and tropical soils. Pp. 5-32 *In* Dynamics of soil organic matter in tropical ecosystems. The project, Honolulu, Hawaii.
- Tracy, B.F. and D.A. Frank. 1998. Herbivore influence on soil microbial biomass and nitrogen mineralization in a northern grassland ecosystem: Yellowstone National Park. *Oecologia*. 114: 556-562.
- van Veen, J.A., J.N. Ladd, and M.J. Frissel. 1984. Modelling C and N turnover thorough the microbial biomass in soil. *Plant. Soil* 76: 257-274.
- Voroney, R.P., and E.A. Paul. 1984. Determination of k_c and k_n *in situ* for calibration of the chloroform-fumigation-incubatio method. *Soil Biol. Biochem.* 16(1): 9-14.
- Willms, W.D., J.F. Dormaar, B.W. Adams, and H.E. Douwes. 2002. Response of the mixed prairie to protection from grazing. *J. Range Manage.* 55(3): 210-216.
- Willms, W.D., S. Smoliak, and J.F. Dormaar. 1990. Vegetation response to time-controlled grazing on mixed and fescue prairie. *J. Range Manage.* 43: 513-517.
- Willoughby, M.G., M.J. Alexander, and K.M. Sundquist. 1997. Range plant community types and carrying capacity for the montane subregion. 2nd approximation. Environmental Protection Lands and Forest Service. Edmonton, Alberta.
- WinRhizo, 2000. v4.0B. Regents Instruments, Inc. Quebec, Canada.

Yakovchenko, V.P., L.J. Sikora, and P.D. Millner. 1998. Carbon and nitrogen mineralization of added particulate and macroorganic matter. *Soil Biol. Biochem.* 30: 2139-2146.

Zou, X., D.W. Valentine, R.L. Jr. Sanford, and D. Binkley. 1992. Resin-core and buried-bag estimates of nitrogen transformations in Costa Rican lowland rainforests. *Plant. Soil.* 139: 275-283.

CHAPTER 4

Moving Towards Ecological Integrity

"Elk are highly responsive to changes in forage and predator distribution resulting from land use practices and human use patterns. Because of the history of land use, wildlife management and recreational activities in Jasper National Park, elk distribution, behaviour and impacts are no longer natural in some areas of the park. Consequences include elk aggression towards humans, grazing-related impacts on sensitive plant communities, high levels of human-caused elk mortality along transportation corridors, and increasing concentration of elk on smaller parts of the landscape including the Jasper townsite. An integrated, ecologically-based management strategy is needed to correct the root causes of this dysfunction while, in the short term, managing some of its most evident symptoms (JNP 2000)."

Throughout many National Parks, concern is widespread that humans have altered natural processes, such as predator-prey relationships (Mech 1991), migration patterns (Singer *et al.* 2002), and plant-herbivore dynamics (Zeigenfuss *et al.* 2002). Both Yellowstone and Rocky Mountain National Parks initiated a natural regulation policy in 1968, with increasing reliance on harvests outside Park boundaries to control ungulate populations (Singer 2002). In Rocky Mountain NP, however, the presence of a townsite and the absence of natural predators resulted in steadily increasing elk numbers since 1968, raising concern that natural regulation was not possible where anthropogenic influences were the cause of the unbalance (Singer 2002). Similarly, general opinion in Yellowstone reflected that natural regulation could not be realized in a system lacking fire and wolves (Peck 1980), or in the presence of human influence (Craighead 1991).

In both Yellowstone and Rocky Mountain Parks, concern arose over the condition of native ranges, and that high ungulate populations may be overgrazing the grasslands (Coughenour and Singer 1991, Singer 2002, Zeigenfuss and Singer 2002). The term

"overgrazing" is a subjective term often simply defined as "an excess of herbivory that leads to degradation of plant and soil resources (Coughenour and Singer 1991)." In fact, even the definition of ungulate overabundance is difficult (Singer *et al.* 2002), but Park managers use a variety of methods to determine the appropriate number of ungulates, including elk (*Cervus elaphus*), that ranges can sustain. The concept of carrying capacity was initiated by early range managers (Coughenour and Singer 1991), and in a ranching context, refers to the stocking rate resulting in maximal vegetation, livestock, and economic return (Holechek *et al.* 2001). In a National Park, however, the emphasis is not so much on economic return, but is based on food-limitations, and the sustainability of the ecosystem (Coughenour and Singer 1991, Singer *et al.* 2002), or ecological integrity (JNP 2000).

Several approaches were suggested by Singer *et al.* (1991) to help Park managers determine the appropriate number of ungulates for a particular system. First, population-based approaches use modelling to estimate the food-limited ecological carrying capacity (Singer *et al.* 2002), and how predators may further limit ungulates below carrying capacity (Gasaway *et al.* 1992). Second, the allowable use approach focuses on what proportion of available aboveground net primary production (ANPP) can be removed by ungulates and still maintain ecological integrity (Singer *et al.* 2002). Third, the overgrazing approach is a subjective method of determining what degree of change to native vegetation and ground cover is in excess of natural change and is detrimental to the system (Holechek *et al.* 2001, Singer *et al.* 2002). Fourth, the biodiversity approach uses the changes in plant species composition and species richness to determine ungulate abundance (Singer *et al.* 2002). The increaser-decreaser-invasive species concept is

commonly used, with key species acting as indicators of range condition (Holechek *et al.* 2001). Finally, the grazing optimization and sustainability approach focuses on the effect of ungulates not only on aboveground production and plant species composition, but also on ecosystem processes, and is therefore the most complex approach (Singer *et al.* 2002).

In response to rising elk populations in human use areas and concerns over grassland condition with summer elk use, managers in Jasper National Park have used the fourth of Singer *et al.* (1991) methods of determining ecological carrying capacity (Pfeiffer 1948, Trottier 1979, Tannas 1997). Although Tannas (1997) recently determined that elk were reducing vegetation cover and certain increaser species, it was unclear how belowground processes were affected. Even if aboveground production is sustained with grazing (Frank and McNaughton 1993), root and microbial biomass (Hamilton and Frank 2001), and therefore carbon and nitrogen flows, may be affected (Holland and Detling 1990), having implications on long-term sustainability of the ecosystem (Singer *et al.* 2002). Therefore, I proposed to address the concerns regarding grassland condition in Jasper using an ecosystem approach, focusing on the fourth and fifth methods proposed by Singer and colleagues (2002).

I started by looking at the effects of ungulate grazing on aboveground production and plant species composition. Although winter pellet group counts were 94% higher than summer counts, especially at sandy sites, all sites received some degree of year-round use, confirming the hypothesis of Park managers in Jasper. Further, elk pellet group counts increased closer to the town (Chapter 2), again confirming Park managers' perception that winter ranges close to town receive heavy use, despite the removal of 220

elk in 1999-2000 from the townsite area (JNP 2000). Even at this current level of fairly heavy use, total aboveground production was not affected by grazing, although production tended to increase with defoliation intensity. This is in contrast to canopy cover of total vegetation and litter, which were negatively affected by grazing, suggesting that it is important to measure plant biomass not only at a single time period, but as a cumulative factor. In addition, C/N flows from vegetation were disrupted by reduced litter inputs from aboveground to the soil system, although dung may have over-compensated for reductions in litter, thus maintaining microbial biomass and net N mineralization rate.

Because a number of key winter ranges were located on sandy soils, around Jasper Lake, Park managers need to consider soil texture when looking at the effects of grazing. Aboveground standing green and dead plant material were lower at sandy sites than at loamy, as was root biomass and microbial biomass, although total production was unaffected. Suggested mechanisms for lower microbial biomass in sandy soils included reduced C/N inputs to soil, due to reduced above- and below-ground productivity (Tracy and Frank 1998), or increased predation on microbes due to large pore spaces in sandy soils (Hassink *et al.* 1993). Despite increased microbial turnover, however, N mineralization rates were similar in both sandy and loamy soils, although soil mineral N was lower in sandy soils (Chapter 3). These data suggest that N is lost from sandy soils to either leaching (Chapter 3) or to increased plant N uptake (Tracy and Frank 1998). In the case of the latter, ungulates could be drawn to the sandy sites by higher quality forage (Botkin 1990), resulting in the observed 44% higher pellet group counts at sandy sites

compared to loamy. Further, nutrient return via dung deposition may compensate for plant offtake, thereby sustaining grassland processes despite relatively heavy grazing.

Grazing tended to reduce total vegetation and forb cover on both soil types, but the reduction was greater at sandy sites (Chapter 2). However, invasive forbs, primarily Russian thistle (*Salsola kali*), increased with grazing at sandy sites. Similarly, grazing tended to increase species richness at sites with loamy soils, but decreased species richness at the more xeric, sandy sites (Chapter 2). These data suggest, at least from a species richness point of view, that xeric, sandy sites were unable to sustain the same levels of grazing as more mesic grasslands (Hamilton *et al.* 1998). Soil texture, however, had no influence on the effect of grazing on root biomass or microbial biomass and activity (Chapter 2). The lack of response may be due to insufficiently frequent sampling, low overall biomass and nutrient levels in Jasper, or compensation of litter loss by dung C/N inputs.

At both sandy and loamy sites, aboveground cover has remained similar over time, despite reductions in elk numbers and improved precipitation since the 1940's (Chapter 2). Specifically, neither total vegetation cover nor graminoid cover has increased greatly since the 1940's, although it has not decreased (Chapter 2). This lack of change could be attributed to reduced grassland area with succession, which is forcing elk to graze in higher densities today than in the 1940's, or to the xeric, unproductive nature of Jasper's grasslands. Because of their unproductive nature, Jasper's grasslands, especially those on sandy soils, may not be as resistant to changes in species richness and invasive species grazing as more mesic grasslands.

Thus, my results indicate that although elk numbers have decreased since the 1940's, the present grazing intensity is altering at least aboveground vegetation C/N inputs, although C/N inputs from dung may be maintaining belowground processes, and has prevented the recovery of aboveground biomass with ungulate reductions. It is not so much the overabundance of elk in Jasper that is the issue, rather, the concentration of ungulates into small areas. Therefore, I suggest that, in accordance with the Parks' mandate to "increase ecological integrity through natural processes (JNP 2000)," prescribed burns should be used to reduce tree cover on Jasper's grasslands and change elk-herbivore dynamics on Jasper's winter ranges. The results of such management strategy on plant-herbivore dynamics should be monitored consistently, with vegetation surveys at least every 5 years, and elk surveys for numbers and distribution every 2 years. Finally, in accordance with Parks Canada's *Guiding Principles and Operating Policies* (1994) decree that "all practical efforts...be made to prevent the introduction of exotic plants and animals...and to eliminate or contain them where they already exist", I recommend that immediate action be taken to reduce the extent of the Russian thistle invasion, which is threatening the ecological integrity of Jasper's sandy grasslands, and regular vegetation surveys conducted to monitor the results.

Reference List

- Botkin, D. 1990. *Discordant Harmonies*. Oxford University Press. Oxford. 241 pp.
- Coughenour, M.B., and F.J. Singer. 1991. The concept of overgrazing and its application to Yellowstone's northern range. *In The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Eds. R.B. Keiter and M.S. Boyce. Yale University Press, USA.
- Craighead, J.J. 1991. Yellowstone in transition. *In The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Eds. R.B. Keiter and M.S. Boyce. Yale University Press, USA.
- Frank, D.A., and S.J. McNaughton. 1993. Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. *Oecolog.* 96: 157-161.
- Gasaway, E.C., R.D. Boertje, D.V. Grangaard, D.G. Kelleyhouse, R.O. Stephenson, and D.G. Larson. 1992. The role of predation in limiting moose at low densities in Alaska and Yukon and implications for conservation. *Wildlife Monographs*. 20: 1-59.
- Hamilton III, E.W., M.S. Giovannini, S.A. Moses, J.S. Coleman, and S.J. McNaughton. 1998. Biomass and mineral element responses of Serengeti short-grass species to nitrogen supply and defoliation: Compensation requires a critical N. *Oecolog.* 116: 407-418.
- Hamilton, E.W., and D.A. Frank. 2001. Can plants stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. *Ecol.* 82(9): 2397-2402.
- Hassink, J., L.A. Bouwman, K.B. Zwart, J. Bloem, and L. Brussard. 1993. Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils. *Geoderma*. 57: 105-128.
- Holechek, J.L., R.D. Pieper, and C.H. Herbel. 2001. *Range management principles and practices*. Prentice-Hall, Inc., New Jersey, USA.
- Holland, E.A., and J.K. Detling. 1990. Plant response to herbivory and belowground nitrogen cycling. *Ecol.* 71: 1040-1049.
- JNP. 2000. Elk management plan: Jasper National Park.
- Mech, L.D. 1991. Returning the wolf to Yellowstone. *In The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Eds. R.B. Keiter and M.S. Boyce. Yale University Press, USA.

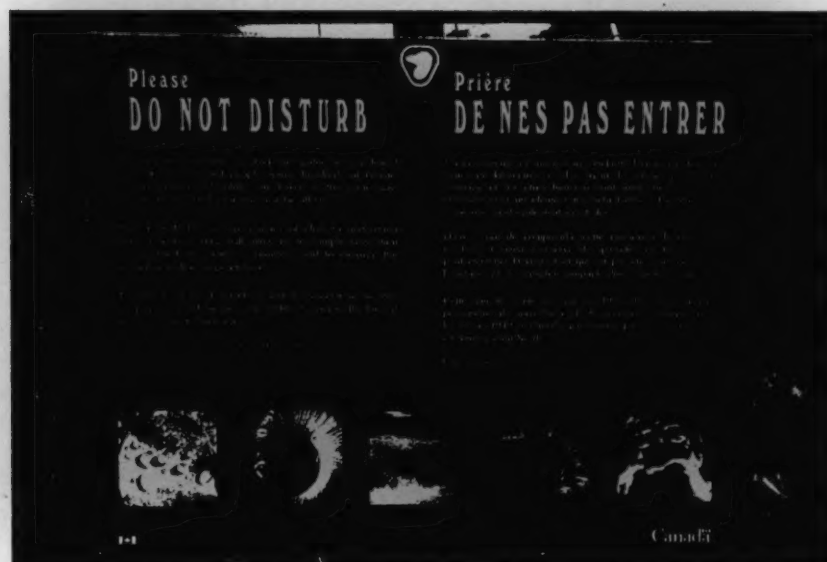
- Peek, J.M. 1980. Natural regulation of ungulates. *Wildl. Soc. Bull.* 8: 217-227.
- Pfeiffer, E.W. 1948. Some factors affecting the winter ranges of Jasper National Park. M.Sc. Thesis, University of British Columbia. Vancouver, British Columbia.
- Rhemtulla, J.M. 1999. Eighty years of change: the montane vegetation of Jasper National Park. M.Sc. Thesis, University of Alberta. Edmonton, Alberta.
- Singer, F.J. 2002. Executive summary of empirical findings. *In* Singer, F.J., and L.C. Zeigenfuss, compilers. Ecological evaluation of the abundance and effects of elk herbivory in Rocky Mountain National Park, Colorado, 1994-1999. Final report to the National Park service, Rocky Mountain National Park on Cooperative Agreement No. 1445-0009-94-1074 (USGS) Subagreement 2 between the National Park Service, Biological Resources Discipline, of U.S. Geological Survey, and Natural Resources Ecology Laboratory, Colorado State University. Open File Report 02-208. 268 pp.
- Singer, F.J., L.C. Zeigenfuss, B. Lubow, and M.J. Rock. 2002. Ecological evaluation of potential overabundance of ungulates in U.S. National Parks: a case study. *In* Singer, F.J., and L.C. Zeigenfuss, compilers. Ecological evaluation of the abundance and effects of elk herbivory in Rocky Mountain National Park, Colorado, 1994-1999. Final report to the National Park service, Rocky Mountain National Park on Cooperative Agreement No. 1445-0009-94-1074 (USGS) Subagreement 2 between the National Park Service, Biological Resources Discipline, of U.S. Geological Survey, and Natural Resources Ecology Laboratory, Colorado State University. Open File Report 02-208. 268 pp.
- Tannas, C. A. 1997. Analysis of range exclosures Jasper National Park. Parks Canada.
- Tracy, B.F. and D.A. Frank. 1998. Herbivore influence on soil microbial biomass and nitrogen mineralization in a northern grassland ecosystem: Yellowstone National Park. *Oecologia*. 114: 556-562.
- Zeigenfuss, L.C., F.J. Singer, and D. Bowden. 2002. Vegetation responses to natural regulation of elk in Rocky Mountain National Park. *In* Singer, F.J., and L.C. Zeigenfuss, compilers. Ecological evaluation of the abundance and effects of elk herbivory in Rocky Mountain National Park, Colorado, 1994-1999. Final report to the National Park service, Rocky Mountain National Park on Cooperative Agreement No. 1445-0009-94-1074 (USGS) Subagreement 2 between the National Park Service, Biological Resources Discipline, of U.S. Geological Survey, and Natural Resources Ecology Laboratory, Colorado State University. Open File Report 02-208. 268 pp.

Appendix A. Site Descriptions, Maps, and Photographs

Jasper Grassland Enclosures

- 1) Cottonwood Point (1995)
- 2) Cottonwood Slough (1995)
- Devona Flats (1956)*
- 3) Devona Hill (1995)
- Disaster Point (1968)*
- 4) Edna (1995)
- 5) Henry House (1956)
- 6) Moberly (1956)
- 7) Richardson (2001)
- 8) Warden's Office (1988)
- 9) Windy Point (1995)

* Not in this study



Cottonwood Point



Figure 1 - Cottonwood Point enclosure, looking east towards Signal Mountain.



Figure 2 - Grazed slopes near Cottonwood Point

Cottonwood Point

Established: 1995

E427333; N5861073, Elev 1106m

Site Description:

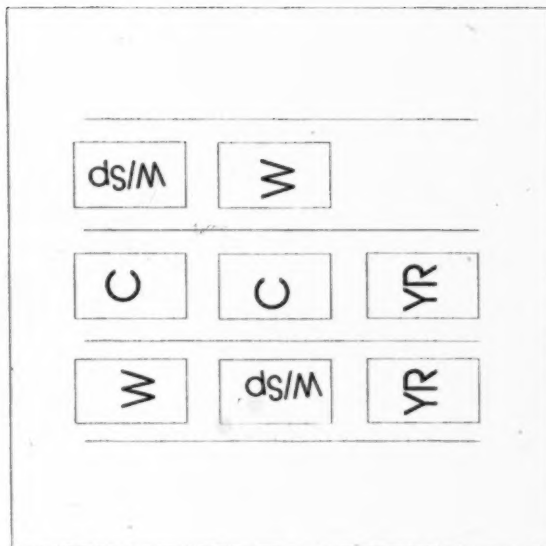
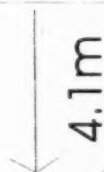
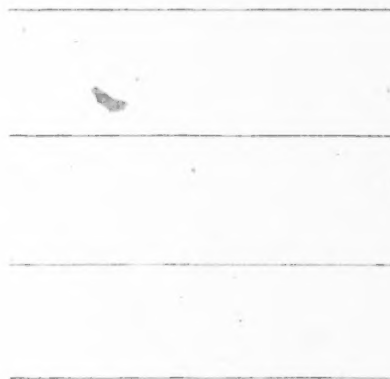
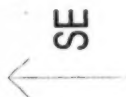
Location - north of town behind Sawridge Hotel

accessed by Trail 2A

Soil texture - loamy to sandy

Transects - marked in 2002

Notes - 25° slope; 126° aspect



○ Rock

Cottonwood Slough



Figure 3- Cottonwood Slough enclosure looking east towards Cottonwood Slough and Pyramid Lake road.

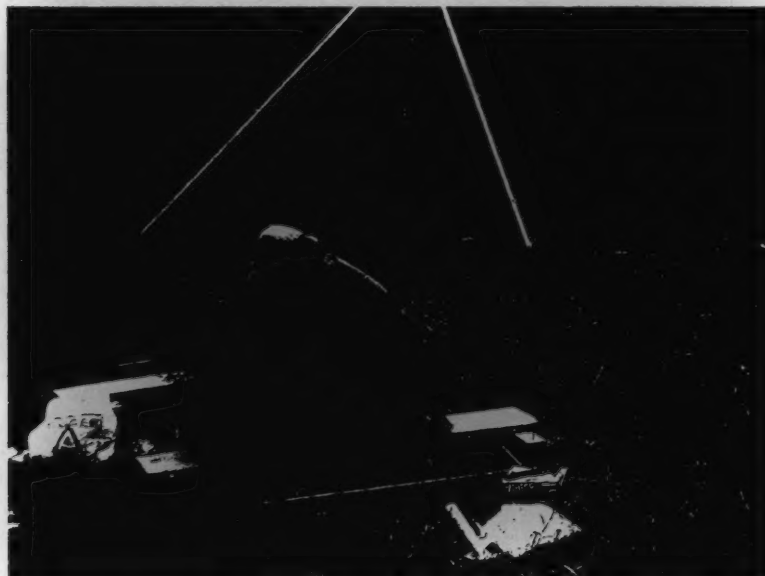


Figure 4 - Inside Cottonwood Slough enclosure collecting soil samples, with black bears watching.

Site Description:

Location - North of Cottonwood Slough

uphill from Trail 6A

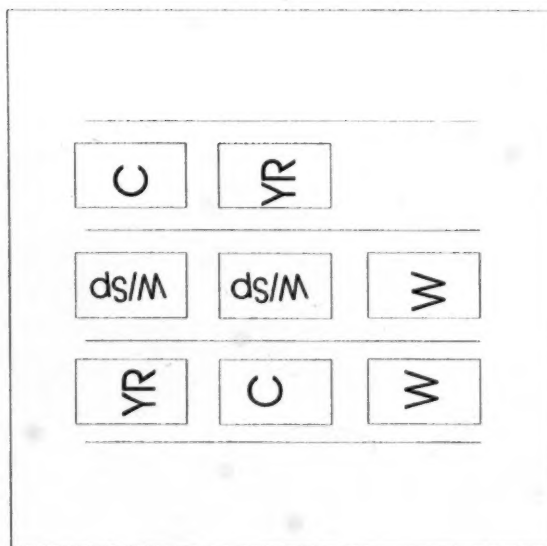
Soil Texture - loamy with cobblestones

Transects - marked in 2002

Notes - 5° slope to south

S

Cottonwood Slough
Established: 1995
E426401; N5861363, Elev 1140m



Horse trail

Devona Hill

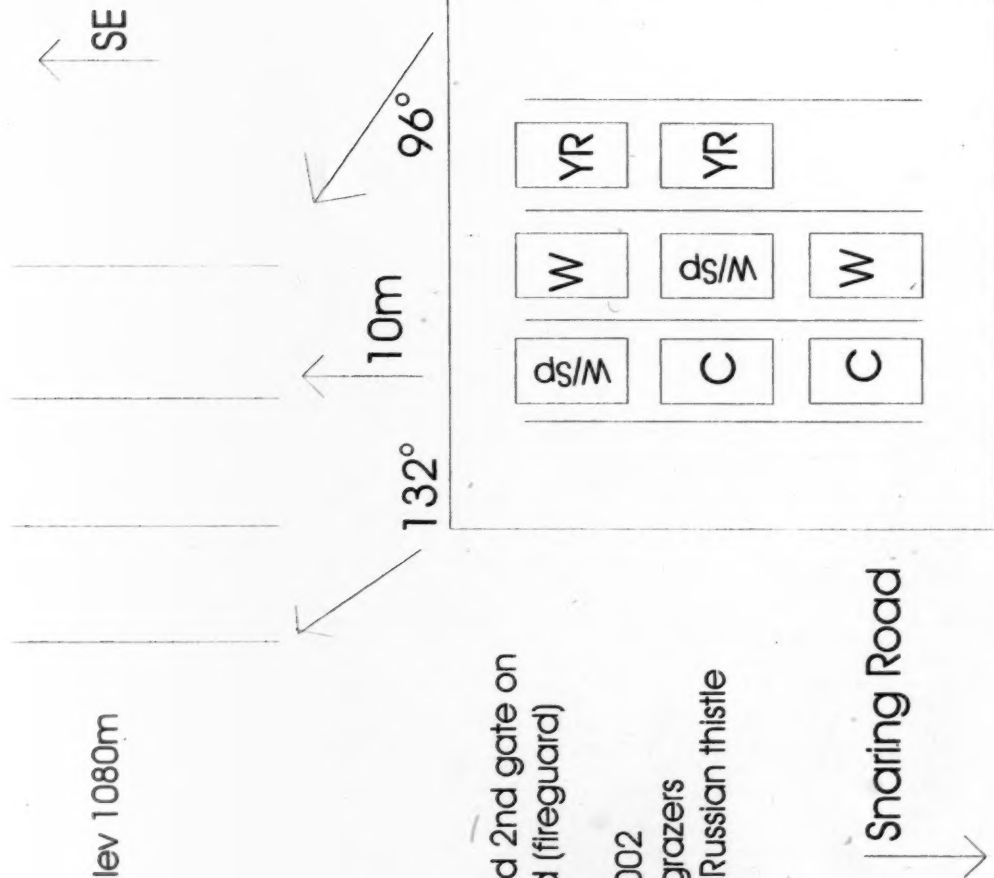


Figure 5 - Devona Hill enclosure,
looking towards Devona fire guard road



Figure 6 - Devona slopes with sheep,
looking south from enclosure

Devona Hill
 Established: 1995
 E432352; N5887350, Elev 1080m



Site Description:
 Location - 500m beyond 2nd gate on
 Snaring Road (fireguard)
 Soil texture- sandy
 Transects - marked in 2002
 Notes - Sheep primary grazers
 Site invaded by Russian thistle

Edna



Figure 6 - Looking west towards Edna exclosure,
with grazed transects in foreground

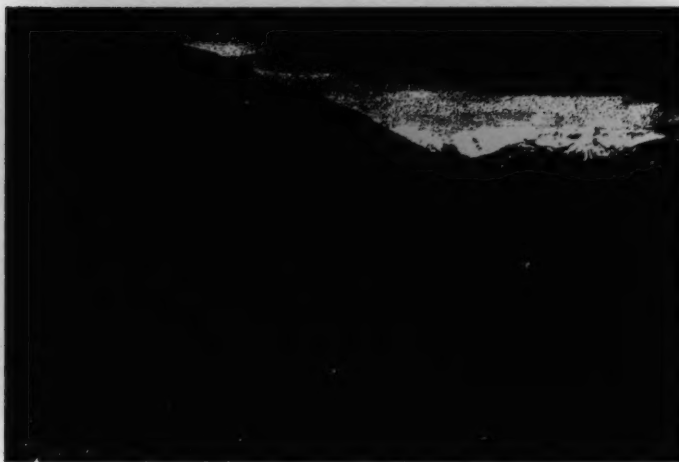


Figure 7 - Looking south from exclosure
on Edna's Knoll, towards Edna Lake and highway

Edna

Established: 1995

E431293; N5881922, Elev. 1080m

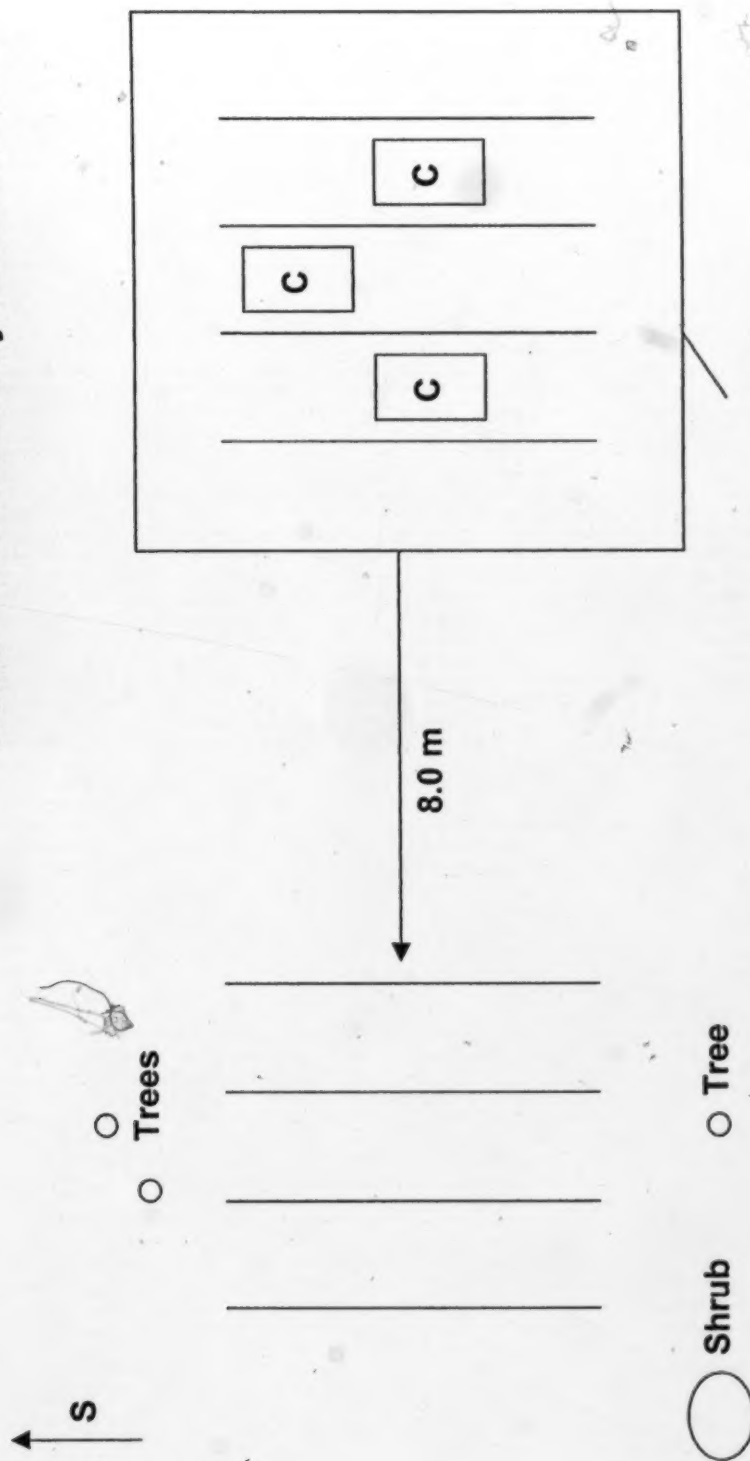
Site Description:

Location-Edna's Knoll, between Edna and Talbot Lakes; E of Highway 16

Soil Texture – Sandy

Transects – marked in 2002

Notes – site invaded by Russian thistle



Henry House



Figure 9 - Henry House enclosure, looking west towards Palisades and Snaring Valley



Figure 10 - Elk herd on Henry House flats, winter 2001

Site Description:

Location - NW of highway 16 and railway

~ 15 km N of town; ~3 km N of Snaring Corner

Soil texture - sandy-loam

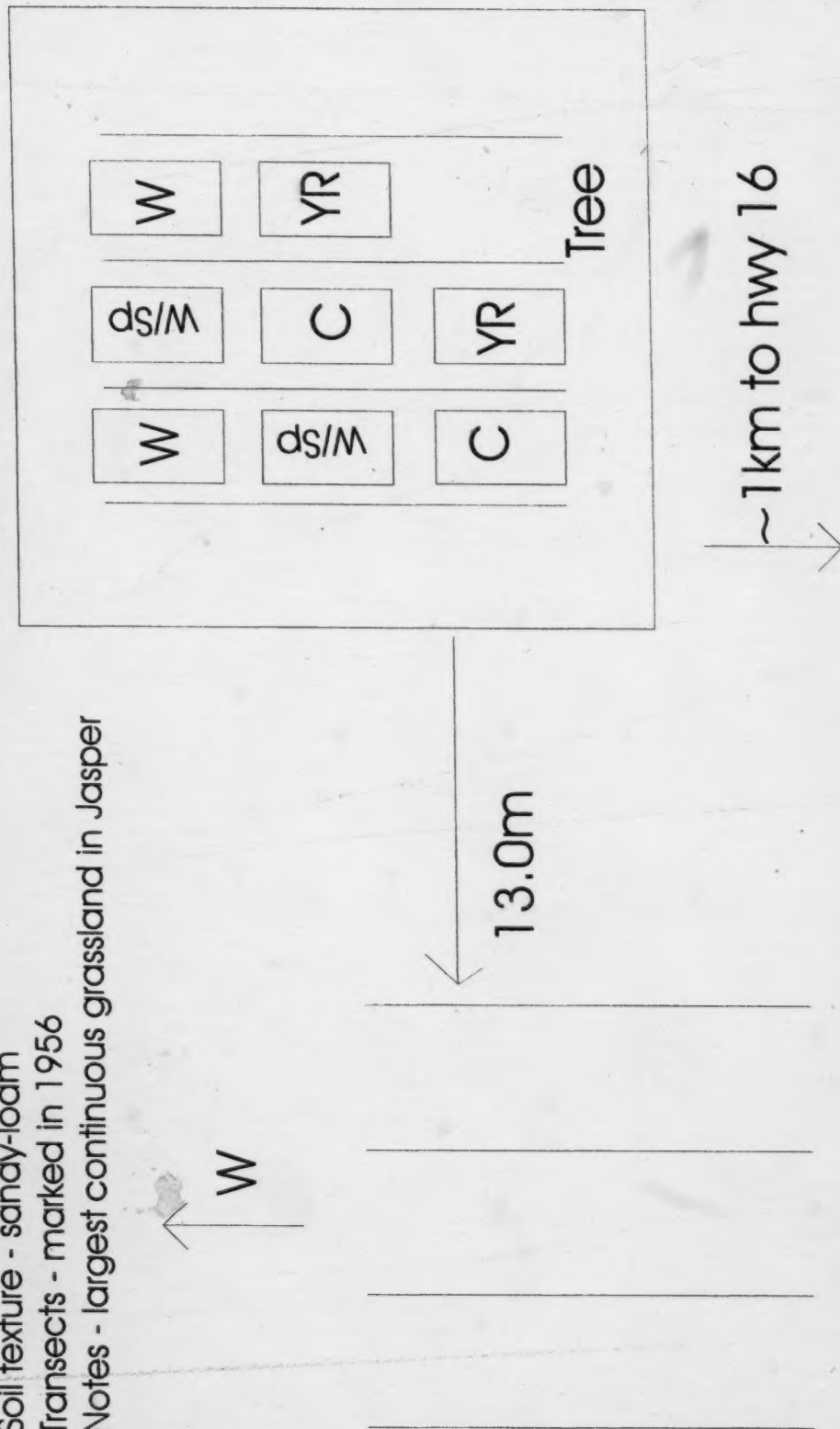
Transects - marked in 1956

Notes - largest continuous grassland in Jasper

Henry House

Established: 1956

E428339; N5872264, Elev 1052m



Moberly



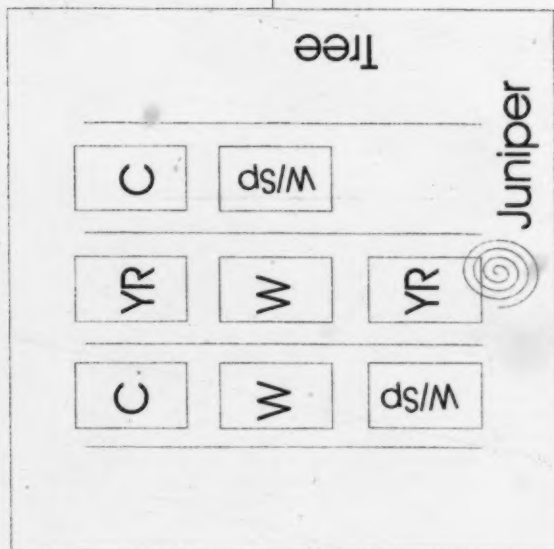
Figure 11 - Moberly enclosure, looking north
with Jasper Lake to right and Snaring Road to left



Figure 12 - Inside Moberly enclosure, looking
towards Snaring Road and Warden's Station

Moberly
 Established: 1956
 E425728; N5879470, Elev 1062m

Site Description:
 Location - 11 km up Snaring Road, on flats
 opposite Snaring Warden's Station
 Soil texture - loamy
 Transects - marked in 1956
 Notes - low moisture regime
 history of domestic use



Power Pole

Snaring Road

Richardson



Figure 13 - Richardson enclosure under construction, July 2001



Figure 14 - Looking east along enclosure fencing, towards grazed transects and Jasper Lake

SE

Richardson

Established: 2001

E425276; N5878336, Elev 1041m

Site Description:

Location - Snaring Road, ~ 500m

South of Moberly Homestead

Soil texture - loamy

Transects- marked in 2001

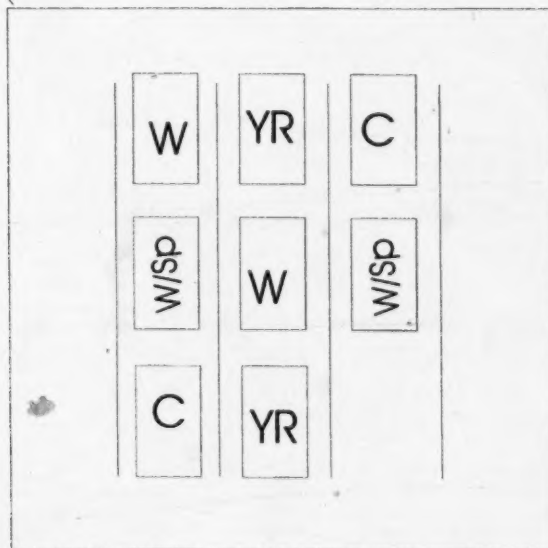
Notes - Lightly grazed Stipa meadow

22.7m

119°



500m to
Moberly Homestead



100

Warden's Office



Figure 15 - Warden's Office enclosure, looking west

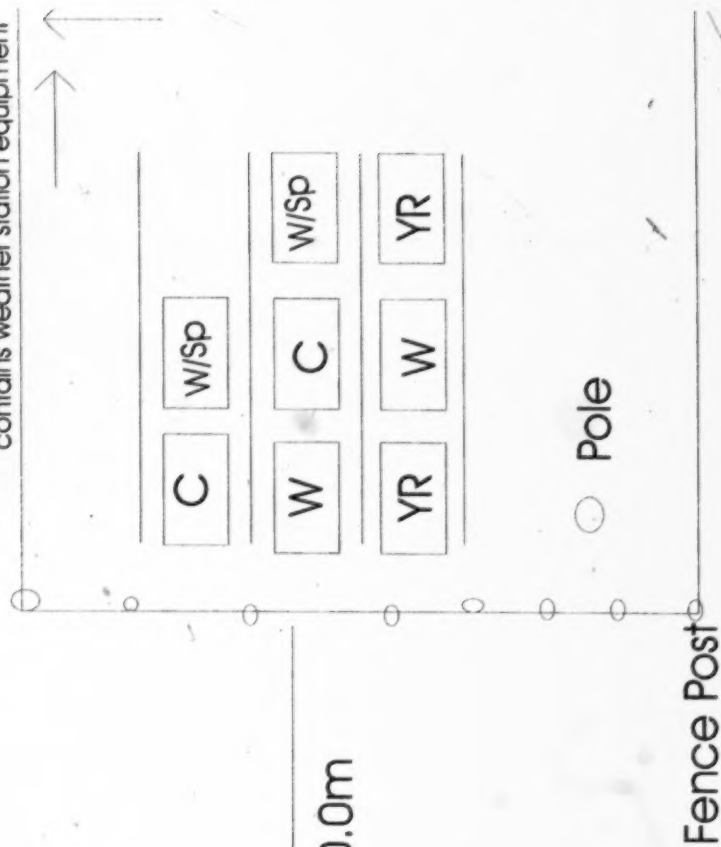
SE

Warden's Office

Established: 1988

E430762; N5864594, Elev 1056m

Site Description:
Location - By 6th Bridge, just before
old Warden's Office
Soil texture - loamy
Transects - marked in 2002
Notes - enclosure is 40m x 40m and
contains weather station equipment



Windy Point



Figure 16 - Windy Point enclosure, looking northeast towards Jasper Lake with Edna's Knoll in background



Figure 17 - Windy Point grassland system

Windy Point

Established: 1995

E428974; N5882401, Elev 1018m

Site Description:

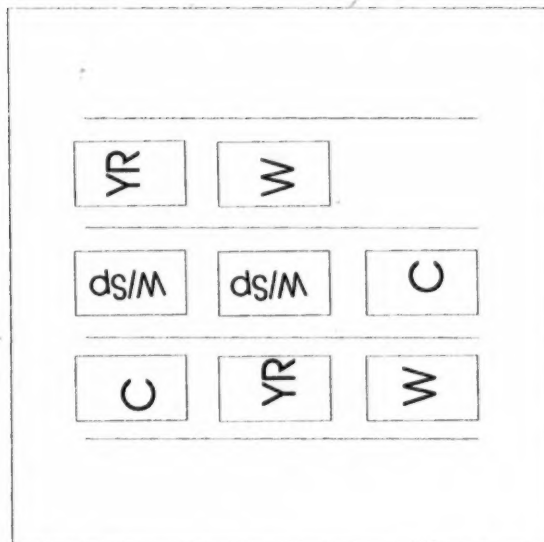
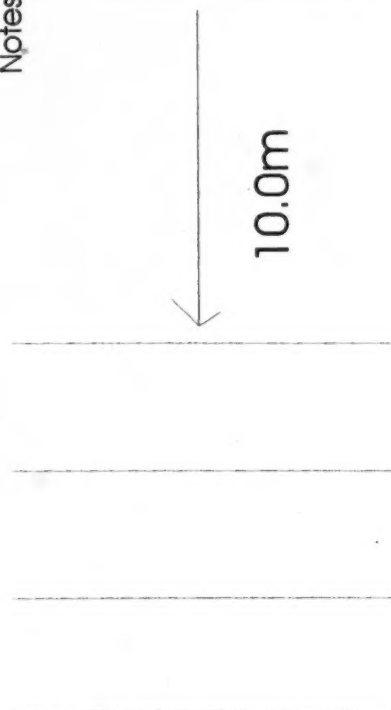
Location - Just after Windy Point on Snaring Road
on grassy flats below road

Soil texture - Sandy-loam

Transects - marked in 2002

Notes - low moisture regime

SE



Appendix B. Complete Vegetation Data

Jasper National Park Grasslands Species List (2002).

Full Species Name	Species Epithet*	Common Name
<i>Achillea millefolium</i>	L.	Common yarrow
<i>Agropyron dasystachyum</i>	Hook. (Scribn.)	Northern wheatgrass
<i>Agropyron trachycaulum</i> (var. <i>subsecudum</i>)	(Link) Malte	Awned wheatgrass
<i>Allium cernuum</i>	Roth	Nodding onion
<i>Amelanchier alnifolia</i>	Nutt.	Saskatoon
<i>Androsace septentrionalis</i>	L.	Fairy candelabra
<i>Anemone multifida</i>	Poir.	Cut-leaved anemone
<i>Anemone patens</i>	L.	Prairie crocus
<i>Antennaria neglecta</i>	Greene	Pussy toes
<i>Antennaria parvifolia</i>	Nutt.	Pussy toes
<i>Arabis holoboelli</i>	Hornem.	Rock cress
<i>Arabis lyalli</i>	S. Wats.	Rock cress
<i>Arabis lyrata</i>	L.	Rock cress
<i>Arctostaphylos uva-ursi</i>	(L.) Spreng.	Kinnickinnick
<i>Artemisia campestris</i>	L.	Sagewort
<i>Artemisia frigida</i>	Willd.	Pasture sagewort
<i>Artemisia tilesii</i>	Ledeb.	Sagewort
<i>Astragulus dasyglottis</i>	Fisch. ex DC.	Milk vetch
<i>Astragulus miser</i>	Dougl. ex Hook.	Timber milk vetch
<i>Astragulus missouriensis</i>	Nutt.	Milk vetch
<i>Astragulus striatus</i>	Nutt.	Milk vetch
<i>Bromus inermis</i> (var. <i>pumpellianus</i>)	Leyss.	Awnless brome
<i>Calamagrostis montanensis</i>	(Scribn.)	Plains reed grass
<i>Calamagrostis rubescens</i>	R.Br.	Purple reed grass
<i>Campanula rotundifolia</i>	L.	Harebell
<i>Carex aurea</i>	Nutt.	Golden sedge
<i>Carex filifolia</i>	Nutt.	Threadleaf sedge
<i>Carex pensylvanica</i>	Lam.	Sun-loving sedge
<i>Carex richardsonii</i>	R.Br.	Sedge
<i>Carex scirpoidea</i>	Michx.	Single spiked sedge
<i>Carex stenophylla</i>	Wahl.	Sedge
<i>Castilleja miniata</i>	Dougl. ex Hook.	Common red paint-brush
<i>Cerastium arvense</i>	L.	Field chickweed
<i>Commandra umbellata</i>	(L.) Nutt.	Bastard toadflax
<i>Elymus innovatus</i>	Beal	Hairy wild rye
<i>Erigeron caespitosus</i>	Nutt.	Tufted fleabane
<i>Erigeron compositus</i>	Pursh	Cut-leaved fleabane
<i>Erucastrum gallicum</i>	(Willd.) Schulz	Dog mustard
<i>Erysimum inconspicuum</i>	(S. Wats.) MacM.	Small-flowered Rocket
<i>Festuca saximontana</i>	Rydb.	Fescue
<i>Fragaria virginiana</i>	Duchesne	Wild strawberry

Full Species Name	Species Epithet*	Common Name
<i>Gaillardia aristata</i>	Pursh	Brown-eyed Susan
<i>Galium boreale</i>	L.	Northern bedstraw
<i>Gentianella amarella</i>	(L.) Borner	Felwort
<i>Hedysarum boreale</i>	Nutt.	Northern sweet vetch
<i>Hierochloa odorata</i>	(L.) Beauv.	Sweet grass
<i>Juniperus communis</i>	L.	Ground juniper
<i>Juniperus horizontalis</i>	Moench	Creeping juniper
<i>Koeleria macrantha</i>	(Ledeb.) J.A. Schultes f.	June grass
<i>Lathyrus ochroleucus</i>	Hook.	Creamy white pea vine
<i>Linum lewesi</i>	Pursh	Wild blue flax
<i>Lithospermum incisum</i>	Lehm.	Puccoon
<i>Minuartia rubella</i>	(Wahl.) Graebn.	Boreal sandwort
<i>Nostoc species</i>		Blue-green alage
<i>Orthocarpus luteus</i>	Nutt.	Yellow owlclover
<i>Oxytropis splendens</i>	Dougl. ex Hook.	Showy loco-weed
<i>Poa compressa</i>	L.	Canada bluegrass
<i>Poa pratensis</i>	L.	Kentucky bluegrass
<i>Poa sandbergii</i>	Vasey	Sandberg bluegrass
<i>Populus tremuloides</i>	Michx.	Trembling aspen
<i>Potentilla fruticosa</i>	L.	Shrubby cinquefoil
<i>Potentilla hippiana</i>	Lehm.	Cinquefoil
<i>Potentilla pensylvanica</i>	L.	Cinquefoil
<i>Pinus banksiana</i>	Lamb.	Jack pine
<i>Rosa woodsii</i>	Lindl.	Common wild rose
<i>Salsola kali</i>	L.	Russian thistle
<i>Senecio streptanthifolius</i>	Greene	Groundsel
<i>Silene cucubalis</i>	Wibel	Bladder campion
<i>Sisyrinchium montanum</i>	Greene	Blue-eyed grass
<i>Solidago spathulata</i>	DC.	Goldenrod
<i>Stipa columbiana</i>	Macoun	Columbia needle grass
<i>Stipa comata</i>	Trin. & Rupr.	Needle and Thread grass
<i>Stipa richardsonii</i>	Link	Richardson needle grass
<i>Symphoricarpos albus</i>	(L.) Blake	Snowberry
<i>Taraxacum officinale</i>	Weber	Common dandelion
<i>Townsendia hookerii</i>	Beaman	Hooker's townsendia
<i>Tragopogon dubius</i>	Scop.	Goat's-beard
<i>Trifolium hybridum</i>	L.	Alsike clover
<i>Vicia americana</i>	Muhl.	Wild vetch
<i>Viola adunca</i>	J.E. Smith	Early blue violet
<i>Zigadenus elegans</i>	Pursh	White camas

* Moss, E.H. 1994. The Flora of Alberta, 2nd Edition. Ed. Packer J.G. University of Toronto Press Incorporated. Toronto, Canada.

Table 1B - Cottonwood Point: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron dasystachyum</i>	13.59	10.97	24	75.00	117.73	32.47
<i>Koeleria macrantha</i>	7.98	8.34	29	90.63	76.01	20.97
<i>Carex stenophylla</i>	0.98	4.27	10	31.25	5.50	1.52
<i>Poa pratensis</i>	1.25	24.75	2	6.25	3.13	0.86
<i>Stipa comata</i>	0.08	0.00	1	3.13	0.14	0.04
Total Graminoids	23.89	13.78				55.86
<i>Achillea millefolium</i>	0.23	0.00	3	9.38	0.72	0.20
<i>Allium cernuum</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Arabis holoboelli</i>	0.09	1.41	2	6.25	0.23	0.06
<i>Artemisia frigida</i>	9.84	14.91	19	59.38	75.85	20.92
<i>Astragulus missouriensis</i>	0.09	1.41	2	6.25	0.23	0.06
<i>Astragulus striatus</i>	3.20	5.91	20	62.50	25.32	6.99
<i>Comandra umbellata</i>	0.23	0.00	3	9.38	0.72	0.20
<i>Erigeron compositae</i>	0.27	1.10	5	15.63	1.05	0.29
<i>Gaillardia aristata</i>	1.97	5.67	15	46.88	13.48	3.72
<i>Galium boreale</i>	1.52	4.87	15	46.88	10.38	2.86
<i>Linum lewesii</i>	0.09	1.41	2	6.25	0.23	0.06
<i>Lithospermum incisum</i>	0.20	1.10	5	15.63	0.80	0.22
<i>Townsendia hookerii</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Tragopogon dubius</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Vicia americana</i>	1.70	4.70	15	46.88	11.66	3.22
Total Fabaceae Forbs	5.00	5.75				10.27
Total Forbs	19.69	14.86				38.92
<i>Rosa woodsii</i>	2.97	6.33	13	40.63	18.92	5.22
Total Shrubs	2.97	6.33				5.22
Avg. No. Species	5.88	1.88				
Total Vegetation	46.55	16.43				
Bare Soil	24.63	19.71				
Moss, lichen	0.00	0.00				

Table 2B - Cottonwood Point: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron trachycaulum</i>	0.16	0.00	2	6.25	0.391	0.31
<i>Agropyron dasystachyum</i>	3.70	5.30	24	75	32.070	25.10
<i>Koeleria macrantha</i>	5.69	6.49	26	81.25	51.266	40.13
<i>Carex stenophylla</i>	0.38	1.07	8	25	1.875	1.47
Total Graminoids	9.92	9.98				67.00
<i>Arabis holoboelli</i>	0.06	0.00	4	12.5	0.221	0.17
<i>Artemisia frigida</i>	3.80	6.01	21	65.625	30.758	24.07
<i>Astragulus missouriensis</i>	0.08	0.00	1	3.125	0.138	0.11
<i>Astragulus striatus</i>	0.33	0.89	5	15.625	1.297	1.02
<i>Comandra umbellata</i>	0.50	0.93	8	25	2.500	1.96
<i>Erigeron compositae</i>	0.16	0.00	2	6.25	0.391	0.31
<i>Gaillardia aristata</i>	0.17	0.76	7	21.875	0.804	0.63
<i>Galium boreale</i>	0.09	1.41	2	6.25	0.234	0.18
<i>Linum lewesii</i>	1.11	7.26	5	15.625	4.385	3.43
<i>Lithospermum incisum</i>	0.23	0.00	3	9.375	0.718	0.56
<i>Tragopogon dubius</i>	0.23	0.00	3	9.375	0.718	0.56
Total Fabaceae	0.41	0.92				1.12
Total Forbs	6.77	6.34				33.00
Avg No. Species	3.78	1.77				
Total Vegetation	16.69	11.40				
Soil	81.17	12.43				
Moss, lichen	0.11	1.15				

Table 3B - Cottonwood Point: Fenced % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron dasystachyum</i>	13.59	20.42	32.47	37.61
<i>Koeleria macrantha</i>	7.98	12.83	20.97	22.39
<i>Carex stenophylla</i>	0.98	2.67	1.51	3.16
<i>Poa compressa</i>	0.00	0.50	0.00	0.17
<i>Poa pratensis</i>	1.25	1.75	0.86	0.85
<i>Stipa comata</i>	0.08	0.58	0.04	0.28
Total Invasive Graminoids	1.25	2.25	0.86	1.02
Total Graminoids	23.89	38.75	55.86	64.46
<i>Achillea millefolium</i>	0.23	1.25	0.20	0.96
<i>Allium cernuum</i>	0.08	0.00	0.04	0
<i>Arabis holoboelli</i>	0.09	0.00	0.06	0.00
<i>Artemisia frigida</i>	9.84	7.95	20.92	11.17
<i>Aster alpinus</i>	0.00	0.08	0.00	0.03
<i>Astragulus dasysglottis</i>	0.00	1.08	0.00	0.64
<i>Astragulus missouriensis</i>	0.09	0.17	0.06	0.08
<i>Astragulus striatus</i>	3.20	0.17	6.99	0.08
<i>Comandra umbellata</i>	0.23	0.33	0.20	0.23
<i>Erigeron compositae</i>	0.27	0.00	0.29	0.00
<i>Erysimum inconspicuum</i>	0.00	0.17	0.00	0.08
<i>Gaillardia aristata</i>	1.97	3.67	3.72	4.69
<i>Galium boreale</i>	1.52	0.85	2.86	0.96
<i>Linum lewesii</i>	0.09	0.00	0.06	0.00
<i>Lithospermum incisum</i>	0.20	0.67	0.22	0.40
<i>Oxytropis splendens</i>	0.00	0.08	0.00	0.03
<i>Taraxacum officinale</i>	0.00	3.17	0.00	3.06
<i>Townsendia hookerii</i>	0.08	0.00	0.04	0.00
<i>Tragopogon dubius</i>	0.08	0.00	0.04	0.00
<i>Vicia americana</i>	1.70	2.25	3.22	2.67
Total Invasive Forbs	0.08	3.17	0.04	3.06
Total Fabaceae Forbs	4.99	3.75	10.27	3.50
Total Forbs	19.69	23.47	38.92	26.16
<i>Rosa woodsii</i>	2.97	7.08	5.22	9.38
Total Shrubs	2.97	7.08	5.22	9.38
Total Vegetation	46.55	69.30		
Bare Soil	26.27	46.08		
Moss, lichen	0.00	0.00		

Table 4B - Cottonwood Point: Grazed % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron trachycaulum</i>	0.16	0.00	0.31	0.00
<i>Agropyron dasystachyum</i>	3.70	12.58	25.10	35.44
<i>Koeleria macrantha</i>	5.69	14.58	40.13	38.02
<i>Carex stenophylla</i>	0.38	1.75	1.47	3.09
Total Graminoids	9.92	28.91	67.00	76.55
<i>Arabis holoboelli</i>	0.06	0.00	0.17	0.00
<i>Artemisia frigida</i>	3.80	6.85	24.07	15.47
<i>Aster alpinus</i>	0.00	0.67	0.00	0.61
<i>Astragulus missouriensis</i>	0.08	0.00	0.11	0.00
<i>Astragulus dasyglottis</i>	0.00	1.17	0.00	1.24
<i>Astragulus striatus</i>	0.33	0.00	1.02	0.00
<i>Comandra umbellata</i>	0.50	0.08	1.96	0.04
<i>Erigeron compositae</i>	0.16	0.00	0.31	0.00
<i>Gaillardia aristata</i>	0.17	1.08	0.63	1.00
<i>Galium boreale</i>	0.09	1.50	0.18	1.38
<i>Linum lewesii</i>	1.11	0.90	3.43	1.44
<i>Lithospermum incisum</i>	0.23	0.67	0.56	0.61
<i>Taraxacum officinale</i>	0.00	0.50	0.00	0.27
<i>Tragopogon dubius</i>	0.23	1.50	0.56	1.38
Total Invasive Forbs	0.23	2.00	0.56	1.65
Total Fabaceae Forbs	0.41	1.17	1.13	1.24
Total Forbs	6.77	14.92	33.00	23.44
Total Vegetation	16.69	43.83		
Bare Soil	81.17	65.17		
Moss, lichen	0.11	0.00		

Table 5B - Cottonwood Point: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	27.6	Decreaser	27.6
<i>Koeleria macrantha</i>	2.4	Increaser	2.4
<i>Carex stenophylla</i>	17.6	Increaser	10.0
<i>Poa pratensis</i>	2.1	Invader	
<i>Stipa comata</i>	0.3	Increaser	0.3
Total Graminoids	50.0		40.3
<i>Achillea millefolium</i>	0.7	Increaser	
<i>Allium cernuum</i>	0.2	Decreaser	
<i>Arabis holoboelli</i>	0.2	Increaser	
<i>Artemisia frigida</i>	19.4	Increaser	5.0
<i>Astragulus missouriensis</i>	0.5	Decreaser	0.5
<i>Astragulus striatus</i>	6.9	Decreaser	6.9
<i>Comandra umbellata</i>	0.3	Increaser	
<i>Erigeron compositae</i>	0.8	Increaser	
<i>Gaillardia aristata</i>	3.6	Increaser	
<i>Galium boreale</i>	3.1	Increaser	
<i>Linum lewesii</i>	0.2	Increaser	
<i>Lithospermum incisum</i>	0.7	Increaser	
<i>Townsendia hookerii</i>	0.5		
<i>Tragopogon dubius</i>	0.2	Invader	
<i>Vicia americana</i>	4.2	Decreaser	4.2
Total Forbs	41.5		16.6
<i>Rosa woodsii</i>	8.4	Increaser	
Total Shrubs	8.4		
% Range Condition:			56.9
Total Vegetation	73.6		
Bare Soil	26.2		
Moss, lichen	0.0		
Litter	35.3		

Table 6B - Cottonwood Point: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable % Composition
<i>Agropyron trachycaulum</i>	19.65	Decreaser	19.6
<i>Agropyron dasystachyum</i>	0.33	Decreaser	0.3
<i>Koeleria macrantha</i>	3.26	Increaser	3.3
<i>Carex stenophylla</i>	31.11	Increaser	10.0
Total Graminoids	54.35		33.2
<i>Arabis holoboelli</i>	1.36	Increaser	
<i>Artemisia frigida</i>	18.05	Increaser	5.0
<i>Astragulas dasyglottis</i>	0.52	Decreaser	0.5
<i>Astragulas missouriensis</i>	1.04	Decreaser	1.0
<i>Astragulas striatus</i>	2.32	Decreaser	2.3
<i>Comandra umbellata</i>	4.64	Increaser	
<i>Erigeron compositae</i>	0.88	Increaser	
<i>Gaillardia aristata</i>	2.28	Increaser	
<i>Galium boreale</i>	1.30	Increaser	
<i>Linum lewesii</i>	8.05	Increaser	
<i>Lithospermum incisum</i>	1.47	Increaser	
<i>Tragopogon dubius</i>	3.50	Invader	
Total Forbs	45.42		8.8
% Range Condition:			42.0
Total Vegetation	18.83		
Bare Soil	83.28		
Moss, lichen	1.50		
Litter	6.41		

Table 7B - Cottonwood Slough: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron trachycaulum</i>	0.11	0.00	7	21.88	0.51	0.09
<i>Carex stenophylla</i>	0.11	1.15	3	9.38	0.33	0.06
<i>Koeleria macrantha</i>	0.25	0.93	8	25.00	1.25	0.22
<i>Poa pratensis</i>	36.88	24.53	32	100.00	368.75	64.30
<i>Poa sandbergii</i>	0.86	5.10	6	18.75	3.72	0.65
<i>Stipa columbiana</i>	0.08	0.00	1	3.13	0.14	0.02
Invasive Grasses	36.88	24.53				0.67
Total graminoids	38.28	23.98				65.34
<i>Achillea millefolium</i>	1.91	4.20	20	62.50	15.07	2.63
<i>Allium cernuum</i>	1.02	7.22	3	9.38	3.11	0.54
<i>Androsace septentrionalis</i>	0.09	1.41	2	6.25	0.23	0.04
<i>Anemone multifida</i>	0.13	1.00	4	12.50	0.44	0.08
<i>Antennaria neglecta</i>	0.63	7.22	3	9.38	1.91	0.33
<i>Arabis holoboelli</i>	0.13	0.00	8	25.00	0.63	0.11
<i>Artemisia campestris</i>	0.16	0.00	2	6.25	0.39	0.07
<i>Artemisia frigida</i>	0.08	0.00	1	3.13	0.14	0.02
<i>Astragulus dasyglottis</i>	0.47	0.00	1	3.13	0.83	0.14
<i>Astragulus striatus</i>	4.22	9.50	19	59.38	32.51	5.67
<i>Castilleja miniata</i>	0.25	1.00	4	12.50	0.88	0.15
<i>Cerastium arvense</i>	0.13	1.00	3	9.38	0.38	0.07
<i>Fragaria virginiana</i>	0.23	0.00	3	9.38	0.72	0.13
<i>Gaillardia aristata</i>	1.77	4.63	15	46.88	12.09	2.11
<i>Galium boreale</i>	0.20	1.10	5	15.63	0.80	0.14
<i>Lathrus ochroleucus</i>	0.08	0.00	1	3.13	0.14	0.02
<i>Linum lewestii</i>	0.08	0.00	1	3.13	0.14	0.02
<i>Potentilla hippiana</i>	3.86	6.66	16	50.00	27.29	4.76
<i>Potentilla pensylvanica</i>	0.50	8.37	3	9.38	1.53	0.27
<i>Senescio streptanthifolius</i>	0.02	0.00	1	3.13	0.03	0.00
<i>Silene cucubalis</i>	0.02	0.00	1	3.13	0.03	0.00
<i>Solidago spathulata</i>	0.30	1.07	7	21.88	1.39	0.24
<i>Taraxacum officinale</i>	0.17	1.15	3	9.38	0.53	0.09
<i>Vicia americana</i>	3.33	6.72	15	46.88	22.79	3.97
<i>Viola adunca</i>	2.84	5.32	22	68.75	23.58	4.11
Total Invasive Forbs	0.19	0.62				0.10
Total Fabaceae Forbs	8.09	9.29				9.81
Total Forbs	22.58	12.77				25.73
<i>Rosa woodsii</i>	8.36	13.83	12	37.50	51.19	8.93
Total Shrubs	8.36	13.83				8.93
Avg. No. Species	7.25	2.16				
Total Vegetation	69.22	26.89				
Bare Soil	7.30	13.90				
Moss, lichen	10.59	15.42				

Table 8B - Cottonwood Slough: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron trachycaulum</i>	0.70	4.17	12	37.5	4.306	1.67
<i>Bromus pumpellianus</i>	0.28	0.84	10	31.25	1.572	0.61
<i>Carex stenophylla</i>	0.17	0.76	6	18.75	0.744	0.29
<i>Hierochloe odorata</i>	0.02	0.00	1	3.125	0.028	0.01
<i>Koeleria macrantha</i>	0.17	1.15	3	9.375	0.526	0.20
<i>Poa pratensis</i>	8.80	8.33	31	96.875	86.583	33.62
<i>Poa sandbergii</i>	0.83	4.83	8	25	4.141	1.61
<i>Stip columbiana</i>	0.06	0.00	4	12.5	0.221	0.09
<i>Stipa richardsonii</i>	0.86	5.10	6	18.75	3.721	1.44
<i>Stipa spp.</i>	0.03	0.00	2	6.25	0.078	0.03
Invasive Grasses	8.80	8.35				33.62
Total graminoids	11.92	8.34				39.57
<i>Achillea millefolium</i>	1.05	3.11	22	68.75	8.680	3.37
<i>Androsace septentrionalis</i>	0.11	0.00	7	21.875	0.512	0.20
<i>Anemone multifida</i>	0.53	0.99	14	43.75	3.514	1.36
<i>Antennaria neglecta</i>	1.03	7.84	4	12.5	3.646	1.42
<i>Arabis holoboelli</i>	0.13	1.00	4	12.5	0.442	0.17
<i>Astragulus dasyglottis</i>	0.75	5.20	7	21.875	3.508	1.36
<i>Astragulus striatus</i>	6.73	6.41	27	84.375	61.859	24.02
<i>Campanula rotundifolia</i>	0.05	0.00	3	9.375	0.144	0.06
<i>Castilleja miniata</i>	0.09	1.41	2	6.25	0.234	0.09
<i>Cerastium arvense</i>	0.08	0.00	1	3.125	0.138	0.05
<i>Fragaria virginiana</i>	0.09	0.87	2	6.25	0.234	0.09
<i>Gailardia aristata</i>	2.25	3.72	26	81.25	20.281	7.87
<i>Galium boreale</i>	0.09	1.41	2	6.25	0.234	0.09
<i>Linum lewesii</i>	0.08	0.00	1	3.125	0.138	0.05
<i>Oxytropis splendens</i>	0.09	1.41	2	6.25	0.234	0.09
<i>Potentilla hippiana</i>	4.42	9.80	19	59.375	34.073	13.23
<i>Potentilla pensylvanica</i>	0.11	1.15	3	9.375	0.335	0.13
<i>Senescio streptanthifolius</i>	0.05	0.00	3	9.375	0.144	0.06
<i>Solidago spathulata</i>	0.59	1.03	14	43.75	3.927	1.52
<i>Taraxacum officinale</i>	0.25	0.93	8	25	1.250	0.49
<i>Trifolium hybridum</i>	0.02	0.00	1	3.125	0.028	0.01
<i>Vicia americana</i>	0.09	1.41	2	6.25	0.234	0.09
Total Invasive Forbs	0.27	0.62				0.50
Total Fabaceae Forbs	7.20	6.62				25.56
Total Forbs	18.69	14.63				55.83
<i>Amelanchier alnifolia</i>	0.94	0.00	2	6.25	2.344	0.91
<i>Juniperus communis</i>	0.47	0.00	1	3.125	0.829	0.32
<i>Rosa woodsii</i>	1.97	7.00	6	18.75	8.525	3.31
<i>Symphoricarpos albus</i>	0.08	0.00	1	3.125	0.138	0.05
Total Shrubs	3.45	6.24				4.60
Avg. No. Species	8.38	2.18				
Total Vegetation	34.06	16.42				
Bare Soil	30.89	15.29				
Moss, lichen	24.08	13.25				

Table 9B - Cottonwood Slough: Fenced % Canopy Cover (1995-2002).

	2002 Avg Cover	1995 Avg Cover	2002 % Prom	1995 % Prom
<i>Agropyron dasystachyum</i>	0.00	0.17	0.00	0.06
<i>Agropyron trachycaulum</i>	0.11	4.83	0.09	4.39
<i>Carex stenophylla</i>	0.11	0.33	0.06	0.17
<i>Koeleria macrantha</i>	0.25	10.50	0.22	14.00
<i>Poa pratensis</i>	36.88	17.33	64.30	21.83
<i>Poa sandbergii</i>	0.86	0.50	0.65	0.31
<i>Stip columbiana</i>	0.08	3.33	0.02	3.25
<i>Stipa richardsonii</i>	0.00	0.58	0.00	0.21
Total Invasive Graminoids	36.88	17.33	64.30	21.83
Total graminoids	38.29	37.57	65.34	44.22
<i>Achillea millefolium</i>	1.91	8.92	2.63	10.77
<i>Allium cernuum</i>	1.02	0.08	0.54	0.02
<i>Androsace septentrionalis</i>	0.09	0.02	0.04	0.01
<i>Anemone multifida</i>	0.13	0.75	0.08	0.38
<i>Antennaria neglecta</i>	0.63	0.08	0.33	0.02
<i>Arabis holoboelli</i>	0.13	0.00	0.11	0.00
<i>Artemisia campestris</i>	0.16	0.00	0.07	0.00
<i>Artemisia frigida</i>	0.08	1.25	0.02	0.31
<i>Astragulus dasyglottis</i>	0.47	3.42	0.14	2.28
<i>Astragulus striatus</i>	4.22	0.00	5.60	0.00
<i>Castilleja miniata</i>	0.25	0.00	0.15	0.00
<i>Cerastium arvense</i>	0.13	0.00	0.07	0.00
<i>Erigeron compositae</i>	0.00	0.25	0.00	0.11
<i>Fragaria virginiana</i>	0.23	0.58	0.13	0.21
<i>Gailardia aristata</i>	1.77	5.42	2.11	5.28
<i>Galium boreale</i>	0.20	0.25	0.14	0.11
<i>Lathrus ochroleucus</i>	0.08	0.00	0.02	0.00
<i>Linum lewesii</i>	0.08	0.08	0.02	0.02
<i>Oxytropis splendens</i>	0.00	0.50	0.00	0.13
<i>Potentilla hippiana</i>	3.86	5.83	4.76	5.69
<i>Potentilla pensylvanica</i>	0.50	0.33	0.27	0.17
<i>Senescio streptanthifolius</i>	0.02	0.08	0.00	0.02
<i>Silene cucubalis</i>	0.02	0.00	0.00	0
<i>Solidago spathulata</i>	0.30	0.58	0.24	0.02
<i>Taraxacum officinale</i>	0.17	14.92	0.09	19.88
<i>Vicia americana</i>	3.33	4.75	3.97	5.61
<i>Viola adunca</i>	2.84	1.17	4.11	0.59
Total Invasive Forbs	0.19	14.92	0.09	19.88
Total Fabaceae Forbs	8.10	8.17	9.73	7.89
Total Forbs	22.62	49.43	25.73	51.88
<i>Rosa woodsii</i>	8.36	5.17	8.93	3.90
Total Shrubs	8.36	5.17	8.93	3.90
Total Vegetation	69.22			
Bare Soil	7.30	10.42		
Moss, lichen	10.59	23.50		

Table 10B - Cottonwood Slough: Grazed % Canopy Cover (1995-2002).

	2002 Avg Cover	1995 Avg Cover	2002 % Prom	1995 % Prom
<i>Agropyron trachycaulum</i>	0.70	9.75	1.67	13.57
<i>Bromus pumpellianus</i>	0.28	0.00	0.61	0.00
<i>Carex stenophylla</i>	0.17	1.33	0.29	1.28
<i>Hierochloe odorata</i>	0.02	0.75	0.01	0.44
<i>Koeleria macrantha</i>	0.17	10.50	0.20	14.29
<i>Poa compressa</i>	0.00	1.50	0.00	0.75
<i>Poa pratensis</i>	8.80	11.50	33.62	12.49
<i>Poa sandbergii</i>	0.83	1.42	1.61	1.09
<i>Stip columbiana</i>	0.06	5.50	0.09	5.53
<i>Stipa richardsonii</i>	0.86	0.08	1.44	0.02
<i>Stipa spp.</i>	0.03	0.00	0.03	0.00
Total Invasive Graminoids	8.80	13.00	33.62	13.24
Total Graminoids	11.92	42.33	39.57	49.46
<i>Achillea millefolium</i>	1.05	9.33	3.37	10.49
<i>Androsace septentrionalis</i>	0.11	0.08	0.20	0.02
<i>Anemone multifida</i>	0.53	0.67	1.36	0.34
<i>Antennaria neglecta</i>	1.03	1.83	1.42	0.92
<i>Arabis holoboelli</i>	0.13	0.00	0.17	0.00
<i>Artemisia frigida</i>	0.00	0.50	0.00	0.15
<i>Astragulus dasyglottis</i>	0.75	6.17	1.36	7.80
<i>Astragulus striatus</i>	6.73	1.00	24.02	0.77
<i>Campanula rotundifolia</i>	0.05	0.00	0.06	0.00
<i>Castilleja miniata</i>	0.09	0.00	0.09	0.00
<i>Cerastium arvense</i>	0.08	0.00	0.05	0.00
<i>Erigeron compositae</i>	0.00	1.00	0.00	0.77
<i>Erysimum inconspicuum</i>	0.00	0.08	0.00	0.02
<i>Fragaria virginiana</i>	0.09	0.00	0.09	0.00
<i>Gaillardia aristata</i>	2.25	1.33	7.87	2.89
<i>Galium boreale</i>	0.09	0.08	0.09	0.02
<i>Linum lewesii</i>	0.08	0.08	0.05	0.02
<i>Oxytropis splendens</i>	0.09	0.50	0.09	0.15
<i>Potentilla hippiana</i>	4.42	5.17	13.23	5.19
<i>Potentilla pensylvanica</i>	0.11	0.00	0.13	0.00
<i>Senescio streptanthifolius</i>	0.05	0.25	0.06	0.75
<i>Solidago spathulata</i>	0.59	2.08	1.52	1.35
<i>Taraxacum officinale</i>	0.25	11.83	0.49	15.73
<i>Trifolium hybridum</i>	0.02	0.00	0.01	0.00
<i>Vicia americana</i>	0.09	2.17	0.09	2.09
Total Invasive Forbs	0.27	11.83	0.50	15.73
Total Fabaceae Forbs	7.66	9.84	25.56	10.81
Total Forbs	18.69	44.15	55.83	49.11
<i>Amelanchier alnifolia</i>	0.94	0.50	0.91	0.15
<i>Juniperus communis</i>	0.47	0.00	0.32	0.00
<i>Rosa woodsii</i>	1.97	2.00	3.31	1.16
<i>Symphoricarpos albus</i>	0.08	0.25	0.05	0.75
Total Shrubs	3.45	2.75	4.60	2.06
Total Vegetation	40.94	89.23		
Bare Soil	30.89	12.67		
Moss, lichen	24.08	24.42		

Table 11B - Cottonwood Slough: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron trachycaulum</i>	0.54	Decreaser	0.50
<i>Carex stenophylla</i>	0.26	Increaser	
<i>Koeleria macrantha</i>	0.66	Increaser	0.66
<i>Poa pratensis</i>	51.39	Invader	
<i>Poa sandbergii</i>	1.89	Increaser	
<i>Stipa columbiana</i>	0.05	Increaser	
Total graminoids	54.79		1.16
<i>Achillea millefolium</i>	2.28	Increaser	2.30
<i>Allium cernuum</i>	1.43	Decreaser	1.43
<i>Androsace septentrionalis</i>	0.15	Increaser	
<i>Anemone multifida</i>	0.42	Increaser	
<i>Antennaria neglecta</i>	0.95	Increaser	
<i>Arabis holoboelli</i>	0.45	Increaser	
<i>Artemisia campestris</i>	0.37	Increaser	
<i>Artemisia frigida</i>	0.34	Increaser	0.34
<i>Astragulus dasyglottis</i>	1.04	Decreaser	1.04
<i>Astragulus striatus</i>	6.39	Decreaser	6.40
<i>Castilleja miniata</i>	0.51	??	
<i>Cerastium arvense</i>	0.16	Increaser	
<i>Fragaria virginiana</i>	0.51	Increaser	
<i>Gailardia aristata</i>	2.22	Increaser	
<i>Galium boreale</i>	0.55	Increaser	
<i>Lathrus ochroleucus</i>	0.09	Decreaser	0.10
<i>Linum lewesii</i>	0.49	Increaser	
<i>Potentilla hippiana</i>	6.71	Increaser	5.00
<i>Potentilla pensylvanica</i>	0.65	Increaser	
<i>Senescio streptanthifolius</i>	0.04	Increaser	
<i>Silene cucubalis</i>	0.07	Invader	
<i>Solidago spathulata</i>	0.71	Increaser	
<i>Taraxacum officinale</i>	0.55	Invader	
<i>Vicia americana</i>	3.50	Decreaser	3.50
<i>Viola adunca</i>	3.35	Increaser	
Total Forbs	33.91		20.11
<i>Rosa woodsii</i>	11.36	Increaser	5.00
Total Shrubs	11.36		5.00
% Range Condition:			26.27
Total Vegetation	72.42		
Bare Soil	7.30		
Moss, lichen	10.53		
Litter	13.72		

Table 12B - Cottonwood Slough: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron trachycaulum</i>	1.7	Decreaser	1.70
<i>Bromus pumpellianus</i>	2.0	Decreaser	2.00
<i>Carex stenophylla</i>	1.2	Increaser	1.20
<i>Hierochloe odorata</i>	0.1	Decreaser	0.10
<i>Koeleria macrantha</i>	0.9	Increaser	0.90
<i>Poa pratensis</i>	23.0	Invader	
<i>Poa sandbergii</i>	2.7	Increaser	2.70
<i>Stip columbiana</i>	0.8	Increaser	0.80
<i>Stipa richardsonii</i>	2.3	Decreaser	2.30
<i>Stipa spp.</i>	0.4	??	
Total graminoids	34.9		11.70
<i>Achillea millefolium</i>	3.7	Increaser	3.70
<i>Androsace septentrionalis</i>	0.8	Increaser	
<i>Anemone multifida</i>	2.9	Increaser	
<i>Antennaria neglecta</i>	1.4	Increaser	
<i>Arabis holoboelli</i>	0.8	Increaser	
<i>Astragalus dasyglottis</i>	1.8	Decreaser	1.80
<i>Astragalus striatus</i>	17.9	Decreaser	17.90
<i>Campanula rotundifolia</i>	0.3	Decreaser	0.30
<i>Castilleja miniata</i>	0.5	??	
<i>Cerastium arvense</i>	0.3	Increaser	
<i>Fragaria virginiana</i>	0.4	Increaser	
<i>Gailardia aristata</i>	7.2	Increaser	5.00
<i>Galium boreale</i>	0.5	Increaser	
<i>Linum lewesii</i>	0.2	Increaser	
<i>Oxytropis splendens</i>	0.3	Increaser	
<i>Potentilla hippiana</i>	10.3	Increaser	5.00
<i>Potentilla pensylvanica</i>	0.5	Increaser	
<i>Senescio streptanthifolius</i>	0.3	Increaser	
<i>Solidago spathulata</i>	2.5	Increaser	
<i>Taraxacum officinale</i>	0.8	Invader	
<i>Trifolium hybridum</i>	0.2	Invader	
<i>Vicia americana</i>	0.4	Decreaser	0.40
Total Forbs	54.1		34.10
<i>Amelanchier alnifolia</i>	3.2	Decreaser	3.20
<i>Juniperus communis</i>	1.9	??	
<i>Rosa woodsii</i>	5.8	Increaser	
<i>Symphoricarpos albus</i>	0.2	Increaser	
Total Shrubs	11.0		3.20
% Range Condition:			49.00
Total Vegetation	15.9		
Bare Soil	18.7		
Moss, lichen	18.7		
Litter	12.9		

Table 13B - Devona Hill: Fenced % Canopy Cover (2002).

	Avg cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron dasystachyum</i>	23.95	17.71	32	100.00	239.53	50.31
<i>Calamagrostis montanensis</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Carex filifolia</i>	0.94	0.00	2	6.25	2.34	0.49
<i>Carex pensylvanica</i>	2.81	6.64	15	46.88	19.26	4.04
<i>Koeleria macrantha</i>	7.52	8.41	29	90.63	71.55	15.03
Total graminoids	35.23	17.97				69.88
<i>Artemisia frigida</i>	6.36	16.76	15	46.88	43.54	9.14
<i>Campanula rotundifolia</i>	0.16	0.00	2	6.25	0.39	0.08
<i>Erigeron caespitosa</i>	8.30	6.36	27	84.38	76.21	16.01
<i>Linum lewesii</i>	1.28	0.95	22	68.75	10.62	2.23
<i>Lithospermum incisum</i>	0.08	0.00	1	3.13	0.14	0.03
<i>Salsola kali</i>	2.67	4.16	4	12.50	9.45	1.98
<i>Senescio streptanthifolius</i>	0.58	0.88	9	28.13	3.07	0.64
Invasive Forbs	2.67	4.16				1.98
Total forbs	19.42	14.53				30.12
Avg. No. Species	5.66	1.38				
Total Vegetation	54.66	21.06				
Bare Soil	1.72	6.60				
Moss, lichen	0.00	0.00				

Table 14B - Devona Hill: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plot w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	3.66	5.32	25	78.125	32.317	13.87
<i>Agropyron trachycaulum</i>	0.17	1.15	3	9.375	0.526	0.23
<i>Bromus pumpellianus</i>	0.16	0.81	7	21.875	0.731	0.31
<i>Calamagrostis montanensis</i>	2.28	5.27	15	46.875	15.619	6.70
<i>Carex pensylvanica</i>	2.06	5.70	13	40.625	13.146	5.64
<i>Koeleria macrantha</i>	2.53	3.53	28	87.5	23.678	10.16
Total graminoids	10.86	7.97				36.92
<i>Artemisia frigida</i>	1.11	3.72	14	43.75	7.338	3.15
<i>Comandra umbellata</i>	0.19	0.71	8	25	0.938	0.40
<i>Erigeron caespitosus</i>	1.41	0.99	26	81.25	12.676	5.44
<i>Linum lewesii</i>	0.20	1.10	5	15.625	0.803	0.34
<i>Salsola kali</i>	12.50	11.96	32	100	125.000	53.65
<i>Senescio streptanthifolius</i>	0.06	0.00	4	12.5	0.221	0.09
Invasive Forbs	12.50	11.96				53.65
Total forbs	15.47	12.22				63.08
<i>Nostoc spp.</i>	10.31	6.15	32		58.336	25.04
Avg. No. Species	5.59	1.32				
Total Vegetation	26.33	11.78				
Bare Soil	62.19	14.66				
Moss, lichen	9.53	6.30				

Table 15B - Devona Hill: Fenced % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg cover	Avg Cover	% Prom	% Prom
<i>Carex pensylvanica</i>	2.81	2.08	4.04	1.27
<i>Agropyron dasystachyum</i>	23.95	33.92	50.31	34.61
<i>Calamagrostis montanensis</i>	0.02	0.00	0.01	0.00
<i>Carex filifolia</i>	0.94	0.00	0.49	0.00
<i>Koeleria macrantha</i>	7.52	25.00	15.03	25.97
Total graminoids	35.23	61.00	69.88	61.85
<i>Artemisia frigida</i>	6.36	2.50	9.14	1.52
<i>Campanula rotundifolia</i>	0.16	0.00	0.08	0.00
<i>Erigeron caespitosa</i>	8.30	9.50	16.01	8.98
<i>Erucastrum gallicum</i>	0.00	3.50	0.00	2.34
<i>Linum lewesii</i>	1.28	7.75	2.23	7.91
mustard?	0.00	0.25	0.00	0.08
<i>Lithospermum incisum</i>	0.08	0.00	0.03	0.00
<i>Salsola kali</i>	2.67	16.50	1.98	17.14
<i>Senescio streptanthifolius</i>	0.58	0.42	0.64	0.18
Invasive Forbs	2.67	16.50	1.98	17.15
Total forbs	19.41	40.42	30.12	38.15
Total Vegetation	54.64			
Bare Soil	1.72			
Moss, lichen	0.00			

Table 16B - Devona Hill: Grazed % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Carex pensylvanica</i>	2.06	0.50	5.64	0.10
<i>Agropyron dasystachyum</i>	3.66	35.92	13.87	37.72
<i>Agropyron trachycaulum</i>	0.17	0.00	0.23	0.00
<i>Bromus pumpellianus</i>	0.16	0.00	0.31	0.00
<i>Calamagrostis montanensis</i>	2.28	0.83	6.70	0.37
<i>Koeleria macrantha</i>	2.53	20.83	10.16	22.27
Total graminoids	10.86	58.58	36.92	60.56
<i>Arabis lyrata</i>	0.00	0.08	0.00	0.02
<i>Artemisia frigida</i>	1.11	5.38	3.15	4.53
<i>Campanula rotundifolia</i>	0.00	0.08	0.00	0.02
<i>Comandra umbellata</i>	0.19	0.00	0.40	0.00
<i>Erigeron caespitosus</i>	1.41	9.00	5.44	8.57
<i>Linum lewesii</i>	0.20	6.75	0.34	6.14
<i>Salsola kali</i>	12.50	19.17	53.65	20.13
<i>Senescio streptanthifolius</i>	0.06	0.17	0.09	0.05
Invasive Forbs	12.50	19.17	53.65	20.13
Total forbs	19.32	40.63	63.08	39.46
<i>Nostoc spp.</i>	10.31		18.75	
Total Vegetation	26.33			
Bare Soil	62.19	12.17		
Moss, lichen	9.53	9.67		

Table 17B - Devona Hill: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	45.86	Decreaser	45.86
<i>Calamagrostis montanensis</i>	0.06	Decreaser	0.06
<i>Carex filifolia</i>	1.28	Decreaser	1.28
<i>Carex pensylvanica</i>	4.12	Increaser	4.12
<i>Koeleria macrantha</i>	15.75	Increaser	10.00
Total graminoids	67.07		61.32
<i>Artemisia frigida</i>	9.60	Increaser	5.00
<i>Campanula rotundifolia</i>	0.19	Decreaser	0.19
<i>Erigeron caespitosus</i>	13.75	Increaser	5.00
<i>Linum lewesii</i>	3.34	Increaser	
<i>Lithospermum incisum</i>	0.13	Increaser	
<i>Salsola kali</i>	4.97	Invader	
<i>Senescio streptanthifolius</i>	0.73	Increaser	
Total forbs	32.70		10.19
% Range Condition:			71.51
Total Vegetation	95.23		
Bare Soil	1.72		
Moss, lichen	0.00		
Litter	43.84		

Table 18B - Devona Hill: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	11.93	Decreaser	11.93
<i>Agropyron trachycaulum</i>	1.28	Decreaser	1.28
<i>Bromus pumpellianus</i>	0.57	Decreaser	0.57
<i>Calamagrostis montanensis</i>	10.29	Decreaser	10.29
<i>Carex pensylvanica</i>	6.42	Increaser	5
<i>Koeleria macrantha</i>	14.44	Increaser	10
Total graminoids	44.93		39.07
<i>Artemisia frigida</i>	4.73	Increaser	4.73
<i>Comandra umbellata</i>	1.35	Increaser	
<i>Erigeron caespitosa</i>	8.45	Increaser	5
<i>Linum lewesii</i>	1.23	Increaser	
<i>Salsola kali</i>	38.42	Invader	
<i>Senescio streptanthifolius</i>	0.60	Increaser	
Total forbs	54.77		9.73
% Range Condition:			48.8
Total Vegetation	28.20		
Bare Soil	62.19		
Moss, lichen	10.31		
Litter	8.09		

Table 19B - Edna: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	0.89	4.71	8	25.00	4.45	1.06
<i>Bromus pumpellianus</i>	2.16	5.14	19	59.38	16.62	3.97
<i>Calamagrostis montanensis</i>	10.13	9.68	29	90.63	96.39	23.03
<i>Elymus innovatus</i>	0.09	1.41	2	6.25	0.23	0.06
<i>Koeleria macrantha</i>	0.25	1.00	4	12.50	0.88	0.21
<i>Stipa columbiana</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Carex filifolia</i>	12.14	16.39	25	78.13	107.31	25.64
<i>Carex scirpoidea</i>	0.11	1.15	3	9.38	0.33	0.08
Total Graminoids	25.78	15.05				54.05
<i>Antennaria neglecta</i>	0.47	0.00	1	3.13	0.83	0.20
<i>Arabis lyrata</i>	0.73	5.52	6	18.75	3.18	0.76
<i>Artemisia campestris</i>	1.70	2.75	28	87.50	15.93	3.81
<i>Artemisia frigida</i>	3.80	9.67	17	53.13	27.67	6.61
<i>Artemisia tillesii</i>	0.25	1.00	4	12.50	0.88	0.21
<i>Campanula rotundifolia</i>	6.41	6.76	26	81.25	57.75	13.80
<i>Comandra umbellata</i>	2.59	3.50	28	87.50	24.26	5.80
<i>Erigeron caespitosus</i>	3.13	7.06	29	90.63	29.75	7.11
<i>Galium boreale</i>	0.09	1.41	2	6.25	0.23	0.06
<i>Linum lewesii</i>	0.59	0.79	22	68.75	4.92	1.18
<i>Lithospermum incisum</i>	0.44	1.04	8	25.00	2.19	0.52
<i>Salsola kali</i>	1.39	4.97	15	46.88	9.52	2.27
<i>Senescio streptanthifolius</i>	1.98	3.88	7	21.88	9.28	2.22
<i>Solidago spathulata</i>	0.52	1.00	9	28.13	2.73	0.65
<i>Zigadenus elegans</i>	0.47	0.00	1	3.13	0.83	0.20
Invasive Forbs	1.39	4.97				2.27
Total Forbs	24.56	15.35				45.39
<i>Potentilla fruticosa</i>	0.94	0.00	2	6.25	2.34	0.56
<i>Arctostaphylos uva-ursi</i>	6.31	27.55	12	37.50	38.66	9.24
Total Shrubs	7.25	18.42				9.80
<i>Nostoc spp.</i>	3.84	4.60				
Avg. No. Species	10.13	1.86				
Total Vegetation	57.59	21.19				
Bare Soil	1.38	1.01				
Moss, lichen	13.14	9.88				

Table 20B - Edna: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plot w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	7.06	6.27	32	100.00	70.63	31.85
<i>Bromus pumpellianus</i>	0.22	1.03	6	18.75	0.95	0.43
<i>Carex filifolia</i>	6.83	6.57	8	25.00	34.14	15.40
<i>Carex scirpoidea</i>	0.13	1.00	4	12.50	0.44	0.20
<i>Koeleria macrantha</i>	0.38	1.07	8	25.00	1.88	0.85
Total Graminoids	14.61	7.36				48.71
<i>Arabis holoboelli</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Arabis lyrata</i>	0.48	10.25	2	6.25	1.21	0.55
<i>Artemisia campestris</i>	2.75	4.41	23	71.88	23.31	10.51
<i>Artemisia frigida</i>	1.45	3.14	20	62.50	11.49	5.18
<i>Artemisia tillesii</i>	1.42	3.26	18	56.25	10.66	4.81
<i>Campanula rotundifolia</i>	0.19	1.15	4	12.50	0.66	0.30
<i>Comandra umbellata</i>	0.91	3.95	13	40.63	5.78	2.60
<i>Erigeron caespitosa</i>	1.89	2.70	28	87.50	17.69	7.97
<i>Galium boreale</i>	0.81	5.07	7	21.88	3.80	1.71
<i>Linum lewesii</i>	0.84	0.98	22	68.75	7.00	3.15
<i>Salsola kali</i>	3.84	6.56	10	31.25	21.49	9.69
<i>Senescio streptanthifolius</i>	0.83	0.92	25	78.13	7.32	3.30
<i>Solidago spathulata</i>	0.38	1.07	8	25.00	1.88	0.85
<i>Townsendia hookerii</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Voila adunca</i>	0.02	0.00	1	3.13	0.03	0.01
Invasive Forbs	3.84	6.56				9.69
Total Forbs	15.84	11.25				50.67
<i>Potentilla fruticosa</i>	0.55	2.67	2	6.25	1.37	0.62
Total Shrubs	0.55	2.67				0.62
<i>Nostoc spp.</i>	2.72	4.00				
Avg. No. Species	8.25	1.63				
Total Vegetation	31.00	13.72				
Bare Soil	30.39	13.41				
Moss, lichen	21.48	13.33				

Table 21B - Edna: Fenced % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron dasystachyum</i>	0.89	15.92	0.97	19.85
<i>Bromus pumpellianus</i>	2.16	3.33	3.63	2.94
<i>Calamagrostis montanensis</i>	10.13	2.33	21.08	1.50
<i>Elymus innovatus</i>	0.09	0.00	0.05	0.00
<i>Koeleria macrantha</i>	0.25	12.42	0.19	15.48
<i>Stipa columbiana</i>	0.02	0.00	0.01	0.00
<i>Carex filifolia</i>	12.14	6.92	23.47	6.10
<i>Carex scirpoidea</i>	0.11	0.00	0.07	0.00
<i>Carex spp.</i>	0.00	0.25	0.00	0.10
Total Graminoids	25.78	41.17	49.48	45.97
<i>Antennaria neglecta</i>	0.47	0.00	0.18	0.00
<i>Arabis lyrata</i>	0.73	1.42	0.70	0.85
<i>Artemisia campestris</i>	1.70	16.67	3.48	20.78
<i>Artemisia frigida</i>	3.80	1.30	6.05	0.84
<i>Artemisia tillesii</i>	0.25	0.00	0.19	0.00
<i>Campanula rotundifolia</i>	6.41	5.43	12.63	4.95
<i>Comandra umbellata</i>	2.59	2.92	5.31	2.57
<i>Erigeron caespitosa</i>	3.13	8.67	6.51	9.67
<i>Galium boreale</i>	0.09	0.00	0.05	0.00
<i>Linum lewesii</i>	0.59	3.75	1.08	3.31
<i>Lithospermum incisum</i>	0.44	0.50	0.48	0.11
<i>Salsola kali</i>	1.39	3.25	2.08	2.34
<i>Senescio streptanthifolius</i>	1.98	7.08	2.03	8.06
<i>Solidago spathulata</i>	0.52	1.08	0.60	0.43
<i>Zigadenus elegans</i>	0.47	0.00	0.18	0.00
Invasive Forbs	1.39	3.25	2.08	2.34
Total Forbs	24.56	52.07	41.55	53.91
<i>Potentilla fruticosa</i>	0.94	0.50	0.51	0.11
<i>Arctostaphylos uva-ursi</i>	6.31	0.00	8.45	0.00
Total Shrubs	7.25	0.50	8.96	0.11
<i>Nostoc spp.</i>	3.84		4.35	
Total Vegetation	51.28	93.74		
Bare Soil	1.38	17.33		
Moss, lichen	13.14	13.17		

Table 22B - Edna: Grazed % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron dasystachyum</i>	7.06	12.08	31.85	15.72
<i>Koeleria macrantha</i>	0.38	15.67	0.85	20.38
<i>Bromus pumpellianus</i>	0.22	2.92	0.43	2.19
<i>Carex filifolia</i>	6.83	5.75	15.40	4.32
<i>Carex scirpoidea</i>	0.13	1.25	0.20	0.30
<i>Carex spp.</i>	0.00	0.83	0.00	0.44
Total Graminoids	14.61	44.67	48.71	49.73
<i>Arabis holoboelli</i>	0.02	0.00	0.11	0.00
<i>Arabis lyrata</i>	0.48	0.00	4.90	0.00
<i>Arabis spp.</i>	0.50	1.27	5.01	1.00
<i>Artemisia campestris</i>	2.75	11.00	7.54	12.53
<i>Artemisia frigida</i>	1.45	5.25	5.18	5.29
<i>Artemisia tillesii</i>	1.42	0.00	4.81	0.00
<i>Campanula rotundifolia</i>	0.19	4.52	0.30	4.15
<i>Comandra umbellata</i>	0.91	1.83	2.60	1.51
<i>Erigeron caespitosus</i>	1.89	12.00	7.97	15.38
<i>Galium boreale</i>	0.81	0.00	1.71	0.00
<i>Linum lewesii</i>	0.84	3.83	3.15	3.64
<i>Salsola kali</i>	3.84	0.67	9.69	0.27
<i>Senescio streptanthifolius</i>	0.83	4.92	3.30	5.72
<i>Solidago spathulata</i>	0.38	1.17	0.85	0.55
<i>Townsendia hookerii</i>	0.02	0.00	0.01	0.00
<i>Voila adunca</i>	0.02	0.00	0.01	0.00
Invasive Forbs	3.84	0.67	9.69	0.27
Total Forbs	15.84	46.54	50.67	50.06
<i>Potentilla fruticosa</i>	0.55	0.50	0.62	0.12
Total Shrubs	0.55	0.50	0.62	0.12
<i>Nostoc spp.</i>	2.72		5.82	
Total Vegetation	31.00	91.71		
Bare Soil	30.39	20.25		
Moss, lichen	21.48	15.50		

Table 23 - Edna: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	0.13	Decreaser	0.13
<i>Bromus pumpellianus</i>	4.20	Decreaser	4.20
<i>Calamagrostis montanensis</i>	20.07	Decreaser	20.07
<i>Carex filifolia</i>	22.76	Decreaser	22.76
<i>Carex scirpoidea</i>	0.16	Decreaser	0.16
<i>Elymus innovatus</i>	0.19	Decreaser	0.19
<i>Koeleria macrantha</i>	0.84	Increaser	0.84
<i>Stipa columbiana</i>	0.04	Increaser	0.04
Total Graminoids	48.40		48.39
<i>Antennaria neglecta</i>	0.59	Increaser	
<i>Arabis lyrata</i>	2.74	Increaser	
<i>Artemisia campestris</i>	3.52	Increaser	
<i>Artemisia frigida</i>	5.28	Increaser	5.00
<i>Artemisia tillesii</i>	0.47	Increaser	
<i>Campanula rotundifolia</i>	11.35	Decreaser	11.35
<i>Comandra umbellata</i>	5.07	Increaser	
<i>Erigeron caespitosa</i>	3.79	Increaser	
<i>Galium boreale</i>	0.08	Increaser	
<i>Linum lewesii</i>	1.57	Increaser	
<i>Lithospermum incisum</i>	0.08	Increaser	
<i>Salsola kali</i>	2.46	Invader	
<i>Senescio streptanthifolius</i>	3.37	Increaser	
<i>Solidago spathulata</i>	1.37	Increaser	
<i>Zigadenus elegans</i>	0.47	Increaser	
Total Forbs	42.20		16.35
<i>Arctostaphylos uva-ursi</i>	7.03	Increaser	
<i>Potentilla fruticosa</i>	2.09	Increaser	
Total Shrubs	9.12		0.00
		% Range Condition:	64.74
Total Vegetation	74.02		
Bare Soil	1.38		
Moss, lichen	13.53		
Litter	15.09		

Table 24B - Edna: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	20.21	Decreaser	20.21
<i>Bromus pumpellianus</i>	1.29	Decreaser	1.29
<i>Carex filifolia</i>	22.24	Decreaser	22.24
<i>Carex scirpoidea</i>	0.59	Decreaser	0.59
<i>Koeleria macrantha</i>	1.33	Increaser	1.33
Total Graminoids	45.66		45.66
<i>Arabis lyrata</i>	0.69	Increaser	
<i>Artemisia campestris</i>	8.71	Increaser	
<i>Artemisia frigida</i>	5.95	Increaser	5.00
<i>Artemisia tillesii</i>	4.33	Increaser	
<i>Campanula rotundifolia</i>	0.64	Decreaser	0.64
<i>Comandra umbellata</i>	2.84	Increaser	
<i>Erigeron caespitosa</i>	7.43	Increaser	5.00
<i>Galium boreale</i>	2.31	Increaser	
<i>Linum lewesii</i>	2.75	Increaser	
<i>Salsola kali</i>	9.55	Invader	
<i>Senescio streptanthifolius</i>	3.77	Increaser	
<i>Solidago spathulata</i>	2.11	Increaser	
<i>Townsendia hookerii</i>	0.23	?	
Total Forbs	51.31		10.64
<i>Potentilla fruticosa</i>	2.56	Increaser	
Total Shrubs	2.56		0.00
% Range Condition:			56.30
Total Vegetation	33.38		
Bare Soil	15.47		
Moss, lichen	15.47		
Litter	6.38		

Table 25B - Henry House: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w spp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	15.02	13.00	32	100.00	150.16	29.86
<i>Bromus pumpellianus</i>	0.55	0.00	7	21.88	2.56	0.51
<i>Calamagrostis montanensis</i>	0.47	0.00	1	3.13	0.83	0.16
<i>Carex scirpoidea</i>	0.08	0.00	1	3.13	0.14	0.03
<i>Carex stenophylla</i>	0.14	0.89	5	15.63	0.56	0.11
<i>Festuca saximontana</i>	0.95	4.05	12	37.50	5.84	1.16
<i>Koeleria macrantha</i>	2.30	3.87	21	65.63	18.61	3.70
Total Graminoids	19.50	12.93				35.53
<i>Androsace septentrionalis</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Anemone multifida</i>	0.06	0.00	4	12.50	0.22	0.04
<i>Anemone patens</i>	1.98	5.90	12	37.50	12.15	2.42
<i>Antennaria parvifolia</i>	25.33	16.19	32	100.00	253.28	50.37
<i>Arabis holoboelli</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Artemisia campestris</i>	0.28	1.10	6	18.75	1.22	0.24
<i>Artemisia frigida</i>	0.47	0.00	1	3.13	0.83	0.16
<i>Astragulus striatus</i>	2.20	14.74	5	15.63	8.71	1.73
<i>Campanula rotundifolia</i>	2.28	6.65	10	31.25	12.75	2.54
<i>Erigeron caespitosus</i>	0.08	0.00	1	3.13	0.14	0.03
<i>Linum lewesii</i>	3.66	6.04	24	75.00	31.66	6.30
<i>Senescio streptanthifolius</i>	0.08	0.00	5	15.63	0.31	0.06
<i>Solidago spathulata</i>	0.48	1.04	11	34.38	2.84	0.56
Total Fabaceae Forbs	2.20	7.42				1.73
Total Forbs	36.94	17.13				64.47
<i>Pinus banksiana</i>	0.08	0.44	1	3.13	0.14	0.03
Total Shrubs	0.08	0.44				0.03
<i>Nostoc spp.</i>	0.79	0.76	7	21.88	3.67	0.73
Avg. No. Species	5.97	1.53				
Total Vegetation	56.52	20.49				
Bare Soil	3.56	5.09				
Moss, lichen	17.89	12.54				

Table 26B - Henry House: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	0.28	1.10	6	18.75	1.22	0.35
<i>Bromus pumpellianus</i>	0.38	1.07	8	25.00	1.88	0.55
<i>Calamagrostis montanensis</i>	0.77	4.92	8	25.00	3.83	1.11
<i>Carex stenophylla</i>	4.50	5.82	29	90.63	42.84	12.47
<i>Festuca saximontana</i>	0.03	0.00	2	6.25	0.08	0.02
<i>Koeleria macrantha</i>	19.61	11.73	32	100.00	196.09	57.06
Total Graminoids	25.56	12.29				71.56
<i>Anemone patens</i>	0.47	0.00	1	3.13	0.83	0.24
<i>Antennaria parvifolia</i>	14.00	11.73	2	6.25	35.00	10.18
<i>Artemisia campestris</i>	4.20	7.60	29	90.63	40.01	11.64
<i>Artemisia frigida</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Artemisia tilesii</i>	0.09	1.41	2	6.25	0.23	0.07
<i>Astragulus striatus</i>	1.77	4.40	9	28.13	9.36	2.72
<i>Campanula rotundifolia</i>	1.38	5.66	10	31.25	7.69	2.24
<i>Erigeron caespitosus</i>	0.48	1.04	11	34.38	2.84	0.83
<i>Gaillardia aristata</i>	0.03	0.00	2	6.25	0.08	0.02
<i>Galium boreale</i>	0.03	0.00	2	6.25	0.08	0.02
<i>Linum lewesii</i>	0.03	0.00	2	6.25	0.08	0.02
<i>Orthocarpus luteus</i>	0.23	0.98	7	21.88	1.10	0.32
<i>Potentilla pensylvanica</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Senescio streptanthifolius</i>	0.09	1.41	2	6.25	0.23	0.07
<i>Solidago spatulata</i>	0.05	0.00	3	9.38	0.14	0.04
Total Fabaceae Forbs	1.77	4.40				2.72
Total Forbs	22.89	15.40				28.44
<i>Nostoc spp.</i>	1.17	0.97	18	56.25	8.75	2.55
Avg. No. Species	6.16	1.44				
Total Vegetation	48.45	15.72				
Bare Soil	2.47	3.43				
Moss, lichen	20.31	12.11				

**Table 27B - Henry House: Fenced % Canopy Cover
(1968-2002).**

	2002	1995	1978	1968
<i>Agropyron dasystachyum</i>	15.02	20.25	5.45	0.00
<i>Bromus pumpellianus</i>	0.55	0.17	1.74	
<i>Calamagrostis monantensis</i>	0.47	5.00	13.54	0.00
<i>Festuca saximontana</i>	0.95	0.00	0.00	
<i>Koeleria macrantha</i>	2.30	3.50	16.35	5.11
<i>Carex scirpoidea</i>	0.08	0.00	0.00	
<i>Carex stenophylla</i>	0.14	0.25	0.00	
Total Graminoids	19.50	29.17	37.08	15.57
<i>Androsace septentrionalis</i>	0.02	0.00	2.07	
<i>Anemone multifida</i>	0.06	0.00	1.18	
<i>Anemone patens</i>	1.98	0.50	0.95	
<i>Antennaria parvifolia</i>	25.33	62.17	20.62	7.36
<i>Arabis holoboelli</i>	0.02	0.00	0.00	
<i>Artemisia campestris</i>	0.28	0.25	3.42	0.00
<i>Artemisia frigida</i>	0.47	1.12	2.30	6.23
<i>Astragulus striatus</i>	2.20	0.00	2.64	0.00
<i>Campanula rotundifolia</i>	2.28	1.83	1.18	0.00
<i>Erigeron caespitosa</i>	0.08	0.08	0.95	
<i>Linum lewesii</i>	3.66	1.42	1.51	
<i>Senescio streptanthifolius</i>	0.08	0.92	11.29	
<i>Solidago spatulata</i>	0.48	3.67	12.75	
Total Forbs	36.94	71.96	60.87	15.79
<i>Pinus banksiana</i>	0.08	0.00	0.00	
<i>Nostoc spp.</i>	0.79			
Soil	3.56	3.57	28.16	
Moss, lichen	17.89	2.27	58.62	29.96
Litter	19.40		18.80	

Table 28B - Henry House: Grazed (1968-2002).

	2002	1995	1978	1968
<i>Agropyron dasystachyum</i>	0.28	3.67	3.76	
<i>Agropyron trachycaulum</i>	0.38	0.08	0.95	
<i>Calamagrostis montanensis</i>	0.77	42.83		6.23
<i>Calamagrostis purpurescens</i>	0.00	0.00	9.94	
<i>Festuca saximontana</i>	0.03	0.08		
<i>Koeleria macrantha</i>	19.61	9.08	19.16	8.26
<i>Carex stenophylla</i>	4.50	1.43	2.86	
Total Graminoids	25.56	57.17	36.68	15.79
<i>Androsace septentrionalis</i>	0.00	0.00	0.95	
<i>Anemone multifida</i>	0.00	0.00	p	
<i>Anemone patens</i>	0.47	0.00	0.95	
<i>Antennaria parvifolia</i>	14.00	19.00	16.35	2.64
<i>Artemisia campestris</i>	4.20	3.42	4.55	0.61
<i>Artemisia frigida</i>	0.02	0.42	2.30	5.45
<i>Artemisia tilesii</i>	0.09	0.00		
<i>Astragulus striatus</i>	1.77	0.27	4.32	
<i>Campanula rotundifolia</i>	1.38	0.25	1.51	
<i>Erigeron caespitosus</i>	0.48	1.75	2.07	
<i>Erigeron grandifolia</i>	0.00	0.00	0.95	
<i>Erigeron spp.</i>	0.00	0.00	0.95	
<i>Erysimum inconspicuum</i>	0.00	0.10	0.61	
<i>Gaillardia aristata</i>	0.03	0.00	3.42	
<i>Galium boreale</i>	0.03	0.17	0.61	
<i>Linum lewesii</i>	0.03	0.00	1.51	
<i>Orthocarpus luteus</i>	0.23	0.00	p	
<i>Potentilla pensylvanica</i>	0.02	0.00		
<i>Senecio streptanthifolius</i>	0.09	0.17	2.64	
<i>Solidago spathulata</i>	0.05	1.50	1.18	
<i>Solidago spp.</i>	0.00	0.00	0.95	
<i>Taraxacum officinale</i>	0.00	0.08	0.61	
Total Forbs	22.89	27.13	46.46	12.19
<i>Nostoc spp.</i>	1.17			
Soil	2.47	2.40	42.80	31.90
Moss, lichen	20.31	2.80	17.30	4.66
Litter	26.70		13.00	35.46

Table 29B - Henry House: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	25.62	Decreaser	25.62
<i>Bromus pumpellianus</i>	1.17	Decreaser	1.17
<i>Calamagrostis montanensis</i>	0.40	Increaser	
<i>Carex scirpoidea</i>	0.10	Decreaser	0.10
<i>Carex stenophylla</i>	0.44	Increaser	0.44
<i>Festuca saximontana</i>	1.37	Decreaser	1.37
<i>Koeleria macrantha</i>	4.48	Increaser	4.48
Total Graminoids	33.58		33.18
<i>Androsace septentrionalis</i>	0.06	Increaser	
<i>Anemone multifida</i>	0.27	Increaser	
<i>Anemone patens</i>	3.98	Increaser	
<i>Antennaria parvifolia</i>	44.04	Increaser	5.00
<i>Arabis holoboelli</i>	0.06	Increaser	
<i>Artemisia campestris</i>	0.81	Increaser	
<i>Artemisia frigida</i>	0.51	Increaser	0.51
<i>Astragulus striatus</i>	4.47	Decreaser	4.47
<i>Campanula rotundifolia</i>	4.43	Decreaser	4.43
<i>Erigeron caespitosus</i>	0.16	Increaser	
<i>Linum lewesii</i>	5.49	Increaser	5.00
<i>Senescio streptanthifolius</i>	0.35	Increaser	
<i>Solidago spathulata</i>	1.55	Increaser	
Total Forbs	66.19		19.41
<i>Pinus banksiana</i>	0.10	??	
Total Shrubs	0.10		
% Range Condition:			52.59
Total Vegetation	58.91		
Bare Soil	3.56		
Moss, lichen	17.89		
Litter	10.25		

Table 30B - Henry House: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	0.77	Decreaser	0.77
<i>Bromus pumpellianus</i>	1.09	Decreaser	1.09
<i>Calamagrostis montanensis</i>	1.75	Increaser	
<i>Carex stenophylla</i>	8.39	Increaser	5.00
<i>Festuca saximontana</i>	0.13	Decreaser	0.13
<i>Koeleria macrantha</i>	43.91	Increaser	10.00
Total Graminoids	56.03		16.99
<i>Anemone patens</i>	0.36	Increaser	
<i>Antennaria parvifolia</i>	27.77	Increaser	5.00
<i>Artemisia campestris</i>	6.67	Increaser	5.00
<i>Artemisia frigida</i>	0.15	Increaser	
<i>Artemisia tilesii</i>	0.25	Increaser	
<i>Astragulus striatus</i>	3.19	Decreaser	3.19
<i>Campanula rotundifolia</i>	1.90	Decreaser	1.90
<i>Erigeron caespitosa</i>	1.53	Increaser	
<i>Gaillardia aristata</i>	0.12	Increaser	
<i>Galium boreale</i>	0.16	Increaser	
<i>Linum lewesii</i>	0.19	Increaser	
<i>Orthocarpus luteus</i>	0.59	Increaser	
<i>Potentilla pensylvanica</i>	0.05	Increaser	
<i>Senescio streptanthifolius</i>	0.38	Increaser	
<i>Solidago spathulata</i>	0.25	Increaser	
Total Forbs	43.57		15.09
% Range Condition:			32.08
Total Vegetation	48.52		
Bare Soil	2.47		
Moss, lichen	20.31		
Litter	7.19		

Table 31B - Moberly: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron dasystachyum</i>	2.20	5.70	14	46.67	15.03	3.74
<i>Agropyron trachycaulum</i>	4.85	13.47	11	36.67	29.37	7.30
<i>Bromus pumpellianus</i>	0.02	0.00	1	3.33	0.03	0.01
<i>Calamagrostis montanensis</i>	2.20	12.14	9	30.00	12.05	3.00
<i>Carex aurea</i>	1.13	7.27	6	20.00	5.07	1.26
<i>Carex stenophylla</i>	0.07	0.00	4	13.33	0.24	0.06
<i>Elymus innovatus</i>	5.83	13.61	8	26.67	30.12	7.49
<i>Koeleria macrantha</i>	0.08	0.00	1	3.33	0.15	0.04
<i>Poa pratensis</i>	11.17	19.14	18	60.00	86.50	21.50
Total Invasive Graminoids	11.17	17.34				21.50
Total Graminoids	27.55	17.50				44.39
<i>Achillea millefolium</i>	0.17	0.00	2	6.67	0.43	0.11
<i>Anemone multifida</i>	0.18	1.15	3	10.00	0.58	0.14
<i>Anemone patens</i>	5.03	12.78	14	46.67	34.38	8.55
<i>Antennaria parvifolia</i>	0.08	0.00	1	3.33	0.15	0.04
<i>Astragalus striatus</i>	0.18	1.15	3	10.00	0.58	0.14
<i>Campanula rotundifolia</i>	0.55	1.00	9	30.00	3.01	0.75
<i>Cerastium arvense</i>	0.85	0.60	11	36.67	5.15	1.28
<i>Comandra umbellata</i>	0.50	0.00	1	3.33	0.91	0.23
<i>Erigeron caespitosus</i>	0.25	0.00	3	10.00	0.79	0.20
<i>Gaillardia aristata</i>	0.27	1.00	4	13.33	0.97	0.24
<i>Galium boreale</i>	8.12	8.65	25	83.33	74.09	18.42
<i>Linum lewisii</i>	0.90	0.94	14	46.67	6.15	1.53
<i>Sisyrinchium montanum</i>	0.17	0.82	6	20.00	0.75	0.19
<i>Solidago spathulata</i>	0.93	4.91	7	23.33	4.51	1.12
<i>Vicia americana</i>	5.02	5.72	26	86.67	46.70	11.61
<i>Viola adunca</i>	3.95	5.18	28	93.33	38.16	9.49
Total Fabaceae Forbs	5.20	5.63				11.75
Total Forbs	27.15	14.04				54.02
<i>Rosa woodsii</i>	1.00	0.00	2	6.67	2.58	0.64
<i>Juniperus communus</i>	2.08	0.00	1	3.33	3.80	0.95
Total Shrubs	3.08	11.85				1.59
Avg. No. Species	7.63	1.97				
Total Vegetation	57.78	22.66				
Bare Soil	0.00	0.00				
Moss, lichen	81.42	28.83				

Table 32B - Moberly: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom
<i>Agropyron dasystachyum</i>	2.31	2.50	31	96.88	22.76	9.31
<i>Agropyron trachycaulum</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Calamagrostis montanensis</i>	5.78	6.30	24	75.00	50.07	20.48
<i>Carex stenophylla</i>	0.72	0.91	22	68.75	5.96	2.44
<i>Koeleria macrantha</i>	4.67	5.62	32	100.00	46.72	19.11
<i>Poa pratensis</i>	0.02	0.00	1	3.13	0.03	0.01
Total Invasive Graminoids	0.02	0.09				0.01
Total Graminoids	13.52	6.52				51.35
<i>Androsace septentrionalis</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Anemone multifida</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Antennaria parvifolia</i>	10.33	19.53	17	53.13	75.28	30.79
<i>Arabis holoboelli</i>	0.03	0.00	2	6.25	0.08	0.03
<i>Artemisia campestris</i>	0.20	0.67	9	28.13	1.08	0.44
<i>Artemisia frigida</i>	0.86	0.98	15	46.88	5.88	2.41
<i>Astragulus striatus</i>	2.59	3.58	24	75.00	22.46	9.19
<i>Campanula rotundifolia</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Comandra umbellata</i>	0.17	1.15	3	9.38	0.53	0.22
<i>Erigeron caespitosa</i>	0.83	1.00	21	65.63	6.71	2.74
<i>Gaillardia aristata</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Linum lewesii</i>	0.23	0.98	7	21.88	1.10	0.45
<i>Orthocarpus luteus</i>	0.08	0.00	1	3.13	0.14	0.06
<i>Oxytropis splendens</i>	0.19	1.15	4	12.50	0.66	0.27
<i>Potentilla pensylvanica</i>	0.19	1.15	4	12.50	0.66	0.27
<i>Senescio streptanthifolius</i>	0.27	0.88	9	28.13	1.41	0.58
<i>Sisyrinchium montanum</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Solidago spathulata</i>	0.30	1.07	7	21.88	1.39	0.57
<i>Taraxacum officinale</i>	0.23	0.98	7	21.88	1.10	0.45
<i>Viola adunca</i>	0.11	1.15	3	9.38	0.33	0.14
Total Invasive Forbs	0.23	0.62				0.45
Total Fabaceae Forbs	2.78	3.49				9.46
Total Forbs	16.69	17.86				48.65
<i>Nostoc spp.</i>	10.48	7.95	31	96.88	103.19	42.21
Avg. No. Species	7.72	1.89				
Total Vegetation	30.20	18.73				
Bare Soil	38.52	24.63				
Moss, lichen	27.11	23.40				

Table 33B - Moberly: Fenced % Canopy Cover (1968-2002).

	2002	1995	1978	1968
<i>Agropyron dasystachyum</i>	2.20	33.42	14.10	3.99
<i>Agropyron trachycaulum</i>	4.85	0.67		
<i>Bromus pumpellianus</i>	0.02	1.75		
<i>Calamagrostis montanensis</i>	2.20	8.00	34.34	28.49
<i>Carex aurea</i>	1.13	0.58		
<i>Carex stenophylla</i>	0.07	0.17		
<i>Koeleria macrantha</i>	0.08	6.42	28.49	7.36
<i>Elymus innovatus</i>	5.83	7.92		
<i>Poa pratensis</i>	11.17	3.50		
Total Graminoids	27.55	62.43	76.94	38.84
<i>Achillea millefolium</i>	0.17	0.00		
<i>Androsace septentrionalis</i>	0.00	0.00	1.51	
<i>Anemone multifida</i>	0.18	1.58	2.30	
<i>Anemone patens</i>	5.03	0.00	3.20	
<i>Antennaria parvifolia</i>	0.08	0.08		0.00
<i>Artemisia campestris</i>	0.00	0.00	1.51	
<i>Artemisia frigida</i>	0.00	0.50		0.00
<i>Astragulus striatus</i>	0.18	0.00	7.70	8.26
<i>Campanula rotundifolia</i>	0.55	0.42	15.00	5.11
<i>Cerastium arvense</i>	0.85	0.00		
<i>Comandra umbellata</i>	0.50	0.00	2.07	
<i>Erigeron caespitosus</i>	0.25	0.08	1.18	
<i>Eryusumum inconspicuum</i>	0.00	0.08		
<i>Gaillardia aristata</i>	0.27	0.00	1.51	
<i>Galium boreale</i>	8.12	15.33	1.18	
<i>Linum lewesii</i>	0.90	3.75	3.42	
<i>Minuartia rubella</i>	0.00	0.58		
<i>Sisyrichium montanum</i>	0.17	0.08	2.64	
<i>Senescio streptanthifolius</i>	0.00	0.00	1.74	
<i>Solidago spathulata</i>	0.93	2.50	3.42	
<i>Taraxacum officinale</i>	0.00	1.92	10.73	
<i>Vicia americana</i>	5.02	0.83		
<i>Viola adunca</i>	3.95	12.92	3.42	
Total Forbs	27.15	41.15	62.54	21.19
<i>Rosa woodsii</i>	1.00	0.50		
<i>Juniperus communus</i>	2.08	0.00		
Total Shrub	3.08	0.50	0.00	0.00
Soil	0.00	0.83	6.68	
Moss, lichen	81.42	18.17	37.04	10.73

Table 34B - Moberly: Grazed % Canopy Cover (1968-2002).

	2002	1995	1978	1968
<i>Agropyron dasystachyum</i>	2.31	18.92	18.38	2.64
<i>Agropyron trachycaulum</i>	0.02	0.00	0.00	
<i>Bromus pumpellianus</i>	0.00	0.00	1.51	
<i>Calamagrostis montanensis</i>	5.78	29.42	10.51	8.48
<i>Carex stenophylla</i>	0.72	0.00	2.07	
<i>Koeleria macrantha</i>	4.67	13.83	24.00	6.57
<i>Poa interior</i>	0.00	0.00	0.95	0.00
<i>Poa pratensis</i>	0.02	0.00	0.00	
Total Graminoids	13.52	62.25	57.42	17.69
<i>Achillea millefolium</i>	0.00	0.08		
<i>Androsece septentrionalis</i>	0.02	0.00	7.36	
<i>Anemone multifida</i>	0.02	1.17		
<i>Antennaria parvifolia</i>	10.33	8.08		
<i>Arabis holoboelli</i>	0.03	0.00		
<i>Artemisia campestris</i>	0.20	2.00	1.18	
<i>Artemisia frigida</i>	0.86	5.42	3.99	9.05
<i>Astragulus dasyglottis</i>	0.00	0.58		
<i>Astragulus striatus</i>	2.59	8.25	2.86	
<i>Campanula rotundifolia</i>	0.02	0.00		
<i>Comandra umbellata</i>	0.17	1.00	4.32	
<i>Erigeron caespitosus</i>	0.83	5.75	8.03	
<i>Gaillardia aristata</i>	0.02	0.00	2.64	
<i>Linum lewesii</i>	0.23	0.58	4.32	
<i>Lithospermum incisum</i>	0.00	0.00	1.18	
<i>Orthocarpus luteus</i>	2.50	0.00		
<i>Oxytropus splendens</i>	0.19	0.00		
<i>Potentilla pensylvanica</i>	0.19	0.03	0.95	
<i>Senescio streptanthifolius</i>	0.27	1.50	6.01	
<i>Sisyrinchium montanum</i>	0.02	0.00		
<i>Solidago spathulata</i>	0.30	1.67	1.74	
<i>Taraxacum officinale</i>	0.23	13.92	2.86	
<i>Viola adunca</i>	0.11	0.17		
Total Forbs	16.69	50.20	47.43	14.10
<i>Nostoc spp.</i>	10.82			
Soil	38.52	18.50		
Moss, lichen	27.11	9.00		

Table 35B - Moberly: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	7.76	Decreaser	7.76
<i>Agropyron trachycaulum</i>	8.95	Decreaser	8.95
<i>Bromus pumpellianus</i>	0.07	Decreaser	0.07
<i>Calamagrostis montanensis</i>	2.08	Increaser	
<i>Carex aurea</i>	1.82	Decreaser	1.82
<i>Carex stenophylla</i>	1.18	Increaser	
<i>Koeleria macrantha</i>	6.61	Increaser	5.00
<i>Poa pratensis</i>	19.09	Invader	
Total Graminoids	47.56		23.60
<i>Achillea millefolium</i>	0.33	Increaser	
<i>Anemone multifida</i>	0.29	Increaser	
<i>Anemone patens</i>	5.28	Increaser	
<i>Antennaria parvifolia</i>	10.43	Increaser	
<i>Artemisia campestris</i>	0.31	Increaser	
<i>Artemisia frigida</i>	0.85	Increaser	0.85
<i>Astragulus striatus</i>	2.95	Decreaser	2.95
<i>Campanula rotundifolia</i>	0.96	Decreaser	0.96
<i>Cerastium arvense</i>	0.48	Increaser	
<i>Comandra umbellata</i>	0.60	Increaser	
<i>Erigeron caespitosa</i>	1.37	Increaser	
<i>Gaillardia aristata</i>	0.58	Increaser	
<i>Galium boreale</i>	8.73	Decreaser	8.73
<i>Linum lewesii</i>	1.94	Increaser	
<i>Sisyrinchium montanum</i>	0.49	Increaser	
<i>Solidago spathulata</i>	2.68	Increaser	
<i>Vicia americana</i>	6.27	Decreaser	6.27
<i>Viola adunca</i>	5.93	Decreaser	5.93
Total Forbs	50.49		25.69
<i>Juniperus communus</i>	2.94	????	
Total Shrubs	2.94		0.00
% Range Condition:			49.29
Total Vegetation	79.17		
Bare Soil	11.00		
Moss, lichen	58.75		
Litter	30.57		

Table 36B - Moberly: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	7.32	Decreaser	7.32
<i>Agropyron trachycaulum</i>	0.18	Decreaser	0.18
<i>Calamagrostis montanensis</i>	20.35	Increaser	
<i>Carex stenophylla</i>	3.76	Increaser	
<i>Koeleria macrantha</i>	8.29	Increaser	5.00
Total Graminoids	39.90		12.50
<i>Androsace septentrionalis</i>	0.20	Increaser	
<i>Anemone multifida</i>	0.13	Increaser	
<i>Antennaria parvifolia</i>	30.67	Increaser	
<i>Arabis holoboelli</i>	0.04	Increaser	
<i>Artemisia campestris</i>	1.40	Increaser	
<i>Artemisia frigida</i>	3.32	Increaser	3.32
<i>Astragulus striatus</i>	10.16	Decreaser	10.16
<i>Comandra umbellata</i>	0.93	Increaser	
<i>Erigeron caespitosa</i>	5.22	Increaser	
<i>Gaillardia aristata</i>	0.23	Increaser	
<i>Linum lewesii</i>	1.29	Increaser	
<i>Orthocarpus luteus</i>	0.20	Increaser	
<i>Oxytropis splendens</i>	0.14	Increaser	
<i>Potentilla pensylvanica</i>	0.80	Increaser	
<i>Senescio streptanthifolius</i>	1.71	Increaser	
<i>Sisyrinchium montanum</i>	0.32	Increaser	
<i>Solidago spathulata</i>	1.45	Increaser	
<i>Taraxacum officinale</i>	1.60	Invader	
<i>Viola adunca</i>	0.73	Decreaser	0.73
Total Forbs	60.54		14.21
% Range Condition:			26.71
Total Vegetation	32.89		
Bare Soil	42.66		
Moss, lichen	26.72		
Litter	1.88		

Table 37B - Richardson: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron trachycaulum</i>	4.42	6.65	19	59.38	34.07	6.11
<i>Bromus pumpellianus</i>	2.14	7.05	9	28.13	11.35	2.04
<i>Carex aurea</i>	0.34	1.03	6	18.75	1.49	0.27
<i>Carex filifolia</i>	1.95	0.00	1	3.13	3.45	0.62
<i>Carex pensylvanica</i>	1.95	5.59	5	15.63	7.72	1.38
<i>Koeleria macrantha</i>	0.02	0.00	1	3.13	0.03	0.00
<i>Poa compressa</i>	0.19	1.15	4	12.50	0.66	0.12
<i>Poa pratensis</i>	22.42	21.46	20	62.50	177.26	31.78
<i>Stipa richardsonii</i>	20.19	23.14	26	81.25	181.97	32.63
Total Invasive Graminoids	22.61	24.32				31.90
Total Graminoids	53.63	22.87				74.95
<i>Anemone multifida</i>	0.70	6.25	4	12.50	2.49	0.45
<i>Anemona patens</i>	0.08	0.00	1	3.13	0.14	0.02
<i>Antennaria parvifolia</i>	11.56	27.30	9	28.13	61.32	10.99
<i>Artemisia campestris</i>	0.23	0.00	3	9.38	0.72	0.13
<i>Artemisia frigida</i>	0.47	0.00	1	3.13	0.83	0.15
<i>Artemisia tilesii</i>	0.16	0.00	2	6.25	0.39	0.07
<i>Astragulus dasyglottis</i>	4.30	17.34	8	25.00	21.48	3.85
<i>Astragulus striatus</i>	1.02	4.42	8	25.00	5.08	0.91
<i>Campanula rotundifolia</i>	2.00	5.81	13	40.63	12.75	2.29
<i>Cerastium arvense</i>	0.22	1.03	6	18.75	0.95	0.17
<i>Comandra umbellata</i>	0.55	1.04	11	34.38	3.21	0.57
<i>Erigeron caespitosa</i>	0.20	1.10	5	15.63	0.80	0.14
<i>Erigeron compositae</i>	0.09	1.41	2	6.25	0.23	0.04
<i>Galium boreale</i>	0.33	0.89	5	15.63	1.30	0.23
<i>Linum lewesii</i>	1.41	5.34	12	37.50	8.61	1.54
<i>Sisyrinchium montanum</i>	0.03	0.00	2	6.25	0.08	0.01
<i>Taraxacum officinale</i>	1.03	7.84	4	12.50	3.65	0.65
<i>Viola adunca</i>	1.78	4.55	16	50.00	12.60	2.26
Total Invasive Forbs	1.03	3.69				0.65
Total Fabaceae Forbs	5.31	11.35				4.76
Total Forbs	26.16	26.61				24.49
<i>Eleagnus comutata</i>	1.02	3.69	3	9.38	3.11	0.56
Total Shrubs	1.02	3.69				0.56
Avg. No. Species	6.44	2.06				
Total Vegetation	80.80	18.96				
Bare Soil	2.10	0.89				
Moss, lichen	76.77	33.27				

Table 38B - Richardson: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron trachycaulum</i>	3.38	7.98	26.00	81.25	30.42	9.59
<i>Bromus pumpellianus</i>	6.53	9.05	22.00	68.75	54.15	17.07
<i>Calamagrostis montanensis</i>	9.22	10.89	31.00	96.88	90.74	28.60
<i>Carex aurea</i>	0.63	7.22	3.00	9.38	1.91	0.60
<i>Carex filifolia</i>	0.08	0.00	1.00	3.13	0.14	0.04
<i>Carex pensylvanica</i>	1.89	6.21	10.00	31.25	10.57	3.33
<i>Koeleria macrantha</i>	0.08	0.00	1.00	3.13	0.14	0.04
<i>Poa pratensis</i>	6.00	8.14	3.00	9.38	18.37	5.79
Total Invasive Graminoids	6.00	7.94				5.79
Total Graminoids	27.80	15.63				59.28
<i>Androsace septentrionalis</i>	0.02	0.00	1.00	3.13	0.03	0.01
<i>Anemone multifida</i>	0.11	1.15	3.00	9.38	0.33	0.11
<i>Anemone patens</i>	0.23	0.00	3.00	9.38	0.72	0.23
<i>Arabis lyrata</i>	0.08	0.00	1.00	3.13	0.14	0.04
<i>Artemisia frigida</i>	0.08	0.00	1.00	3.13	0.14	0.04
<i>Astragalus dasyglottis</i>	0.94	0.00	2.00	6.25	2.34	0.74
<i>Astragalus striatus</i>	1.09	7.22	4.00	12.50	3.87	1.22
<i>Campanula rotundifolia</i>	0.80	0.60	11.00	34.38	4.67	1.47
<i>Comandra rotundifolia</i>	0.81	1.02	16.00	50.00	5.75	1.81
<i>Erigeron caespitosa</i>	0.16	0.00	2.00	6.25	0.39	0.12
<i>Galium boreale</i>	0.80	5.33	6.00	18.75	3.45	1.09
<i>Linum lewesii</i>	7.81	6.34	30.00	93.75	75.64	23.84
<i>Oxytropis splendens</i>	0.08	0.00	1.00	3.13	0.14	0.04
<i>Sisyrinchium montanum</i>	0.25	1.00	4.00	12.50	0.88	0.28
<i>Solidago spathulata</i>	0.08	0.00	1.00	3.13	0.14	0.04
<i>Taraxacum officinale</i>	0.72	5.88	5.00	15.63	2.84	0.90
<i>Vicia americana</i>	0.70	6.25	4.00	12.50	2.49	0.78
<i>Viola adunca</i>	1.73	0.85	5.00	15.63	6.86	2.16
Total Invasive Forbs	0.72	2.71				0.90
Total Fabaceae Forbs	2.81	6.80				2.78
Total Forbs	16.48	9.45				34.93
Avg. No. Species	7.56	1.64				
Total Vegetation	44.28	17.08				
Bare Soil	0.00	0.00				
Moss, lichen	78.91	28.22				

Table 39B - Richardson: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron trachycaulum</i>	6.56	Decreaser	6.56
<i>Bromus pumpellianus</i>	2.81	Decreaser	2.81
<i>Carex aurea</i>	0.31	Decreaser	0.31
<i>Carex filifolia</i>	0.54	Decreaser	0.54
<i>Carex pensylvanica</i>	1.98	???	
<i>Koeleria macrantha</i>	0.04	Increaser	0.04
<i>Poa compressa</i>	0.38	Invader	
<i>Poa pratensis</i>	29.10	Invader	
<i>Stipa richardsonii</i>	24.93	Decreaser	24.93
Total Graminoids	66.64		35.19
<i>Anemone multifida</i>	0.57	Increaser	
<i>Anemona patens</i>	0.07	Increaser	
<i>Antennaria parvifolia</i>	13.91	Increaser	
<i>Artemisia campestris</i>	0.45	Increaser	
<i>Artemisia frigida</i>	0.56	Increaser	0.56
<i>Artemisia tilesii</i>	0.38	Increaser	
<i>Astragulus dasyglottis</i>	4.51	Decreaser	4.51
<i>Astragulus striatus</i>	1.60	Decreaser	1.60
<i>Campanula rotundifolia</i>	2.39	Decreaser	2.39
<i>Cerastium arvense</i>	0.37	Increaser	
<i>Comandra umbellata</i>	1.07	Increaser	
<i>Erigeron caespitosa</i>	0.41	Increaser	
<i>Erigeron compositae</i>	0.14	Increaser	
<i>Galium boreale</i>	0.47	Increaser	
<i>Linum lewesii</i>	1.73	Increaser	
<i>Sisyrinchium montanum</i>	0.09	Increaser	
<i>Taraxacum officinale</i>	1.13	Invader	
<i>Viola adunca</i>	2.35	Increaser	
Total Forbs	32.19		9.06
<i>Eleagnus comutata</i>	1.09	???	
Total Shrubs	1.09		0.00
% Range Condition:			44.25
Total Vegetation	94.84		
Bare Soil	0.33		
Moss, lichen	76.77		
Litter	21.31		

Table 40B - Richardson: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron trachycaulum</i>	7.42	Decreaser	7.42
<i>Bromus pumpellianus</i>	13.83	Decreaser	13.83
<i>Calamagrostis montanensis</i>	19.11	Increaser	
<i>Carex aurea</i>	0.84	Decreaser	0.84
<i>Carex filifolia</i>	0.29	Decreaser	0.29
<i>Carex pensylvanica</i>	6.71	???	
<i>Koeleria macrantha</i>	0.18	Increaser	0.18
<i>Poa pratensis</i>	14.13	Invader	
Total Graminoids	62.52		22.56
<i>Androsace septentrionalis</i>	0.09	Increaser	
<i>Anemone multifida</i>	0.41	Increaser	
<i>Anemone patens</i>	0.59	Increaser	
<i>Arabis lyrata</i>	0.20	Increaser	
<i>Artemisia frigida</i>	0.38	Increaser	0.38
<i>Astragulus dasyglottis</i>	1.88	Decreaser	1.88
<i>Astragulus striatus</i>	2.39	Decreaser	2.39
<i>Astragulus missouriensis</i>	0.22	Decreaser	0.22
<i>Campanula rotundifolia</i>	2.33	Decreaser	2.33
<i>Comandra rotundifolia</i>	2.76	Increaser	
<i>Erigeron caespitosa</i>	0.61	Increaser	
<i>Galium boreale</i>	1.82	Increaser	
<i>Linum lewesii</i>	13.61	Increaser	
<i>Oxytropis splendens</i>	0.23	Increaser	
<i>Sisyrinchium montanum</i>	0.72	Increaser	
<i>Solidago spathulata</i>	0.23	Increaser	
<i>Taraxacum officinale</i>	0.99	Invader	
<i>Vicia americana</i>	1.86	Decreaser	1.86
<i>Viola adunca</i>	6.17	Increaser	
Total Forbs	37.47		9.06
% Range Condition:			31.62
Total Vegetation	92.42		
Bare Soil	0.00		
Moss, lichen	79.30		
Litter	53.75		

Table 41B - Warden's Office: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	7.52	10.61	16	51.61	54.00	14.86
<i>Agropyron trachycaulum</i>	0.19	1.15	4	12.90	0.70	0.19
<i>Bromus pumpellianus</i>	2.79	6.92	12	38.71	17.36	4.78
<i>Calamagrostis purpurescens</i>	3.50	6.60	6	19.35	15.40	4.24
<i>Carex richardsonii</i>	0.02	0.00	1	3.23	0.03	0.01
<i>Carex stenophylla</i>	0.60	1.04	13	41.94	3.86	1.06
<i>Elymus innovatus</i>	6.06	5.83	16	51.61	43.57	11.99
<i>Festuca saximontana</i>	5.66	11.60	18	58.06	43.14	11.87
<i>Koeleria macrantha</i>	0.11	1.15	3	9.68	0.35	0.10
<i>Poa compressa</i>	0.44	0.98	7	22.58	2.07	0.57
<i>Poa pratensis</i>	0.60	6.98	4	12.90	2.14	0.59
Total Invasive Graminoids	1.03	2.77				1.16
Total Graminoids	27.48	16.50				50.27
<i>Achillea millefolium</i>	0.92	4.09	12	38.71	5.72	1.57
<i>Anemone multifida</i>	2.66	5.87	17	54.84	19.71	5.42
<i>Anemone patens</i>	1.53	6.25	4	12.90	5.50	1.51
<i>Antennaria parvifolia</i>	4.69	6.45	20	64.52	37.70	10.38
<i>Arabis holoboelli</i>	0.03	0.00	2	6.45	0.08	0.02
<i>Astragalus missouriensis</i>	1.37	20.21	3	9.68	4.26	1.17
<i>Astragalus striatus</i>	5.61	22.54	15	48.39	39.04	10.75
<i>Campanula rotundifolia</i>	0.48	0.00	1	3.23	0.87	0.24
<i>Cerastium arvense</i>	0.24	0.00	3	9.68	0.75	0.21
<i>Erigeron caespitosus</i>	0.27	1.10	5	16.13	1.10	0.30
<i>Erigeron compositae</i>	0.16	0.82	6	19.35	0.71	0.20
<i>Gaillardia aristata</i>	1.47	12.20	9	29.03	7.91	2.18
<i>Galium boreale</i>	2.03	13.48	7	22.58	9.66	2.66
<i>Linum lewisii</i>	1.02	1.01	19	61.29	7.96	2.19
<i>Oxytropis splendens</i>	0.48	0.00	1	3.23	0.87	0.24
<i>Potentilla pensylvanica</i>	0.18	1.15	3	9.68	0.55	0.15
<i>Senecio streptanthifolius</i>	0.11	1.15	3	9.68	0.35	0.10
<i>Sisyrinchium montanum</i>	0.08	0.00	2	6.45	0.20	0.06
<i>Solidago spathulata</i>	2.58	6.03	16	51.61	18.54	5.10
<i>Taraxacum officinale</i>	0.48	1.05	10	32.26	2.75	0.76
<i>Viola adunca</i>	0.76	5.52	6	19.35	3.34	0.92
Total Invasive Forbs	0.48	0.92				0.76
Total Fabaceae Forbs	7.47	17.56				12.16
Total Forbs	27.18	20.87				46.13
<i>Amelanchier alnifolia</i>	1.05	7.22	3	9.68	3.26	0.90
<i>Populus tremuloides</i>	1.21	0.00	1	3.23	2.17	0.60
<i>Rosa woodsii</i>	1.21	0.00	1	3.23	2.17	0.60
<i>Symphoricarpos albus</i>	1.53	6.25	4	12.90	5.50	1.51
Total Shrubs	5.00	10.29				3.61
Avg. No. Species	8.97	1.72				
Total Vegetation	59.66	23.57				
Bare Soil	2.94	7.47				
Moss, lichen	26.78	19.62				

Table 42B - Warden's Office: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	2.73	2.28	30	93.75	26.48	8.05
<i>Agropyron trachycaulum</i>	0.48	10.25	2	6.25	1.21	0.37
<i>Bromus pumellianus</i>	1.19	3.88	11	34.38	6.96	2.12
<i>Calamagrostis montanensis</i>	0.16	0.00	2	6.25	0.39	0.12
<i>Carex richardsonii</i>	0.17	1.15	3	9.38	0.53	0.16
<i>Carex stenophylla</i>	1.73	2.93	22	68.75	14.38	4.37
<i>Festuca saximontana</i>	0.02	0.00	28	87.50	16.95	5.15
<i>Koeleria macrantha</i>	1.81	0.84	1	3.13	0.03	0.01
Total Graminoids	8.30	5.63				20.34
<i>Allium cernuum</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Androsace septentrionalis</i>	0.05	0.00	3	9.38	0.14	0.04
<i>Anemone multifida</i>	0.66	0.84	10	31.25	3.67	1.11
<i>Antennaria parvifolia</i>	15.47	17.24	32	100.00	154.69	47.01
<i>Arabis holoboelli</i>	0.09	1.41	2	6.25	0.23	0.07
<i>Arabis lyalli</i>	0.11	1.15	3	9.38	0.33	0.10
<i>Astragulus dasyglottis</i>	0.23	0.00	3	9.38	0.72	0.22
<i>Astragulus missouriensis</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Astragulus miser</i>	1.52	5.30	11	34.38	8.89	2.70
<i>Astragulus striatus</i>	4.09	4.90	29	90.63	38.97	11.84
<i>Campanula rotundifolia</i>	0.34	1.03	6	18.75	1.49	0.45
<i>Cerastium arvense</i>	0.09	1.41	2	6.25	0.23	0.07
<i>Erigeron compositae</i>	0.41	1.03	10	31.25	2.27	0.69
<i>Gajardina aristata</i>	0.16	0.00	2	6.25	0.39	0.12
<i>Galium boreale</i>	1.48	3.34	14	43.75	9.82	2.98
<i>Gentianella amarella</i>	0.39	1.05	9	28.13	2.07	0.63
<i>Linum lewesii</i>	0.31	1.04	8	25.00	1.56	0.47
<i>Mimaria rubella</i>	0.03	0.00	2	6.25	0.08	0.02
<i>Oxytropis splendens</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Potentilla pensylvanica</i>	0.56	7.86	3	9.38	1.72	0.52
<i>Senescio streptanthifolius</i>	0.27	1.10	5	15.63	1.05	0.32
<i>Silene cucubaris</i>	0.08	0.00	1	3.13	0.14	0.04
<i>Sisyrinchium montanum</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Solidago spathulata</i>	2.73	5.58	19	59.38	21.07	6.40
<i>Taraxacum officinale</i>	0.55	0.98	15	46.88	3.74	1.14
<i>Viola adunca</i>	1.02	4.00	12	37.50	6.22	1.89
Total Invasive Forbs	0.63	0.94				1.18
Total Fabaceae Forbs	6.00	7.50				14.85
Total Forbs	30.89	19.29				78.99
<i>Rosa woodsii</i>	0.47	0.00	1	3.13	0.83	0.25
<i>Symphoricarpos albus</i>	0.55	8.84	2	6.25	1.37	0.42
Total Shrubs	1.02	3.69				0.67
<i>Nostoc spp.</i>	1.83	1.15	3	9.38	5.61	1.71
Avg. No. Species	9.63	2.32				
Total Vegetation	40.20	22.10				
Bare Soil	41.94	22.02				
Moss, lichen	23.31	21.47				

Table 43B - Warden's Office: Fenced % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron dasystachyum</i>	7.52	18.27	14.86	17.75
<i>Agropyron trachycaulum</i>	0.19	0.50	0.19	0.11
<i>Bromus pumpellianus</i>	2.79	1.17	4.78	0.52
<i>Calamagrostis purpurescens</i>	3.50	2.50	4.24	0.79
<i>Carex richardsonii</i>	0.02	0.00	0.01	0.00
<i>Carex stenophylla</i>	0.60	1.03	1.06	0.69
<i>Elymus innovatus</i>	6.06	8.67	11.99	6.69
<i>Festuca saximontana</i>	5.66	6.42	11.87	6.07
<i>Koeleria macrantha</i>	0.11	2.37	0.10	2.04
<i>Poa compressa</i>	0.44	1.95	0.57	1.37
<i>Poa pratensis</i>	0.60	0.50	0.59	0.11
Total Invasive Graminoids	1.03	2.45	1.16	1.48
Total Graminoids	27.48	43.38	50.27	36.14
<i>Achillea millefolium</i>	0.92	1.02	1.37	0.64
<i>Anemone multifida</i>	2.66	1.27	3.34	0.69
<i>Anemone patens</i>	1.53	0.00	3.97	0.00
<i>Antennaria parvifolia</i>	4.69	30.00	5.72	34.75
<i>Arabis holoboelli</i>	0.03	0.00	0.12	0.00
<i>Aster alpinus</i>	0.00	1.00	0.32	0.32
<i>Astragalus missouriensis</i>	1.37	0.00	1.17	0.00
<i>Astragalus striatus</i>	5.61	6.68	10.75	6.14
<i>Campanula rotundifolia</i>	0.48	0.08	0.24	0.02
<i>Cerastium arvense</i>	0.24	0.50	0.21	0.11
<i>Erigeron caespitosus</i>	0.16	1.00	0.20	0.74
<i>Erigeron compositae</i>	1.47	0.12	2.18	0.05
<i>Gaillardia aristata</i>	2.03	1.00	2.66	0.32
<i>Galium boreale</i>	1.02	2.60	2.19	2.01
<i>Linum lewisii</i>	0.48	0.00	0.24	0.00
<i>Oxytropis splendens</i>	0.18	0.00	0.15	0.00
<i>Potentilla pensylvanica</i>	0.11	0.08	0.10	0.02
<i>Senecio streptanthifolius</i>	0.08	0.10	0.06	0.03
<i>Sisyrinchium montanum</i>	2.58	3.02	5.10	2.33
<i>Solidago spathulata</i>	0.48	11.03	0.76	13.01
<i>Taraxacum officinale</i>	0.27	0.00	0.30	0.00
<i>Viola adunca</i>	0.76	0.00	0.92	0.00
Total Invasive Forbs	0.27	0.00	0.30	0.00
Total Fabaceae Forbs	7.16	6.68	12.07	6.14
Total Forbs	27.18	59.50	46.13	61.18
<i>Amelanchier alnifolia</i>	1.05	3.00	0.90	1.16
<i>Populus tremuloides</i>	1.21	0.00	0.60	0.00
<i>Rosa woodsii</i>	1.21	0.00	0.60	0.00
<i>Symphoricarpos albus</i>	1.53	2.17	1.51	1.18
Total Shrubs	5.00	5.17	3.61	2.34
Total Vegetation	59.66			
Bare Soil	3.31	15.75		
Moss, lichen	26.78	2.10		

Table 44B - Warden's Office: Grazed % Canopy Cover (1995-2002).

	2002 Avg Cover	1995 Avg Cover	2002 % Prom	1995 % Prom
<i>Agropyron dasystachyum</i>	2.73	5.33	8.05	3.49
<i>Agropyron trachycaulum</i>	0.48	1.92	0.37	1.45
<i>Bromus pumpellianus</i>	1.19	5.33	2.12	4.51
<i>Calamagrostis montanensis</i>	0.16	1.00	0.12	0.38
<i>Calamagrostis purpurescens</i>	0.00	0.00	0.00	0.38
<i>Carex richardsonii</i>	0.17	2.50	0.16	1.50
<i>Carex stenophylla</i>	1.73	3.25	4.37	3.25
<i>Elymus innovatus</i>	0.00	1.08	0.00	0.50
<i>Festuca saximontana</i>	0.02	0.25	0.01	0.12
<i>Koeleria macrantha</i>	1.81	12.17	5.15	16.91
<i>Poa sandbergii</i>	0.00	0.50	0.00	0.13
<i>Poa compressa</i>	0.00	0.10	0.00	0.04
<i>Poa pratensis</i>	0.00	2.25	0.00	1.59
Total Invasive Graminoids	8.00	2.35	0.00	1.63
Total Graminoids	8.30	35.68	20.34	34.25
<i>Achillea millefolium</i>	0.00	0.25	0.00	0.12
<i>Allium cernuum</i>	0.08	0.00	0.04	0.00
<i>Androsace septentrionalis</i>	0.05	0.00	0.04	0.00
<i>Anemone multifida</i>	0.66	2.92	1.11	3.49
<i>Antennaria parvifolia</i>	15.47	21.00	47.01	28.09
<i>Arabis holoboelli</i>	0.09	0.00	0.07	0.00
<i>Arabis lyallii</i>	0.11	0.00	0.10	0.00
<i>Astragalus dasyglottis</i>	0.23	4.75	0.22	4.40
<i>Astragalus missouriensis</i>	0.08	0.67	0.04	0.31
<i>Astragalus miser</i>	1.52	0.00	2.70	0.00
<i>Astragalus striatus</i>	4.09	2.85	11.84	2.41
<i>Campanula rotundifolia</i>	0.34	0.08	0.45	0.02
<i>Cerastium arvense</i>	0.09	0.00	0.07	0.00
<i>Erigeron compositae</i>	0.41	1.28	0.69	0.41
<i>Gaillardia aristata</i>	0.16	0.18	0.12	0.08
<i>Galium boreale</i>	1.48	3.25	2.98	3.25
<i>Gentianella amarella</i>	0.39	0.00	0.63	0.00
<i>Linum lewisii</i>	0.31	0.58	0.47	0.41
<i>Minuartia rubella</i>	0.03	0.00	0.02	0.00
<i>Oxytropis splendens</i>	0.08	0.00	0.04	0.00
<i>Potentilla pensylvanica</i>	0.56	0.43	0.52	0.28
<i>Senecio streptanthifolius</i>	0.27	1.22	0.32	1.13
<i>Silene cucubaris</i>	0.08	0.00	0.04	0.00
<i>Sisyrinchium montanum</i>	0.02	0.00	0.01	0.00
<i>Solidago pathulata</i>	2.73	4.58	6.40	4.75
<i>Taraxacum officinale</i>	0.55	11.17	1.14	14.33
<i>Viola adunca</i>	1.02	1.58	1.89	1.27
Total Invasive Forbs	0.63	11.17	1.18	14.33
Total Fabaceae Forbs	6.00	8.27	14.85	7.12
Total Forbs	30.89	56.79	78.99	64.75
<i>Amelanchier alnifolia</i>	0.00	1.00	0.00	0.38
<i>Rosa woodsii</i>	0.47	0.00	0.25	0.00
<i>Symphoricarpos albus</i>	0.55	0.25	0.42	0.12
Total Shrubs	1.02	1.25	0.67	0.50
Total Vegetation	40.21			
Bare Soil	41.94	15.75		
Moss, lichen	23.31	20.33		

Table 45B - Warden's Office: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	13.37	Decreaser	13.37
<i>Agropyron trachycaulum</i>	0.33	Decreaser	0.33
<i>Bromus pumpellianus</i>	4.87	Decreaser	4.87
<i>Calamagrostis purpurescens</i>	6.54	Decreaser	6.54
<i>Carex richardsonii</i>	0.12	Decreaser	0.12
<i>Carex stenophylla</i>	1.12	Increaser	
<i>Elymus innovatus</i>	11.58	Decreaser	11.58
<i>Festuca saximontana</i>	7.45	Decreaser	7.45
<i>Koeleria macrantha</i>	0.33	Increaser	0.33
<i>Poa compressa</i>	0.73	Invader	
<i>Poa pratensis</i>	1.36	Invader	
Total Graminoids	47.80		44.59
<i>Achillea millefolium</i>	1.51	Increaser	
<i>Anemone multifida</i>	5.25	Increaser	
<i>Anemone patens</i>	2.22	Increaser	
<i>Antennaria parvifolia</i>	10.71	Increaser	
<i>Arabis holoboelli</i>	0.14	Increaser	
<i>Astragalus missouriensis</i>	1.40	Decreaser	1.40
<i>Astragalus striatus</i>	6.70	Decreaser	6.70
<i>Campanula rotundifolia</i>	0.88	Decreaser	0.88
<i>Cerastium arvense</i>	1.43	Increaser	
<i>Erigeron compositae</i>	1.37	Increaser	
<i>Gaillardia aristata</i>	1.65	Increaser	
<i>Galium boreale</i>	2.59	Increaser	
<i>Linum lewesii</i>	2.45	Increaser	
<i>Oxytropis splendens</i>	0.95	Increaser	
<i>Potentilla pennsylvanica</i>	0.48	Increaser	
<i>Senecio streptanthifolius</i>	0.35	Increaser	
<i>Sisyrinchium montanum</i>	0.26	Increaser	
<i>Solidago spathulata</i>	3.86	Increaser	
<i>Taraxacum officinale</i>	1.09	Invader	
<i>Viola adunca</i>	0.86	Increaser	
Total Forbs	46.13		8.98
<i>Amelanchier alnifolia</i>	2.21	Decreaser	2.21
<i>Populus tremuloides</i>	0.94	Decreaser	0.94
<i>Rosa woodsii</i>	1.27	Increaser	
<i>Symphoricarpos albus</i>	1.65	Invader	
Total Shrubs	6.07		3.15
		% Range Condition: 56.72	
Total Vegetation	72.58		
Bare Soil	2.50		
Moss, lichen	24.55		
Litter	23.03		

Table 46B - Warden's Office: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	8.27	Decreaser	8.27
<i>Agropyron trachycaulum</i>	0.30	Decreaser	0.30
<i>Bromus pumpellianus</i>	4.76	Decreaser	4.76
<i>Calamagrostis montanensis</i>	0.85	Increaser	
<i>Carex richardsonii</i>	0.60	Decreaser	0.60
<i>Carex stenophylla</i>	4.42	Increaser	
<i>Festuca saximontana</i>	0.13	Decreaser	0.13
<i>Koeleria macrantha</i>	7.28	Increaser	5.00
Total Graminoids	26.61		19.06
<i>Allium cernuum</i>	0.31	Decreaser	0.31
<i>Androsace septentrionalis</i>	0.29	Increaser	
<i>Anemone multifida</i>	2.12	Increaser	
<i>Antennaria parvifolia</i>	30.26	Increaser	
<i>Arabis holoboelli</i>	0.28	Increaser	
<i>Arabis lyalli</i>	0.39	Increaser	
<i>Astragulus dasyglottis</i>	0.58	Decreaser	0.58
<i>Astragulus miser</i>	2.22	Decreaser	2.22
<i>Astragulus striatus</i>	9.87	Decreaser	9.87
<i>Campanula rotundifolia</i>	1.46	Decreaser	1.46
<i>Cerastium arvense</i>	0.37	Increaser	
<i>Erigeron compositae</i>	2.09	Increaser	
<i>Gailardia aristata</i>	0.49	Increaser	
<i>Galium boreale</i>	3.56	Increaser	
<i>Gentianella amarella</i>	1.00	???	
<i>Linum lewesii</i>	1.61	Increaser	
<i>Minuartia rubella</i>	0.15	???	
<i>Oxytropis splendens</i>	0.14	Increaser	
<i>Potentilla pensylvanica</i>	0.82	Increaser	
<i>Senecio streptanthifolius</i>	0.70	Increaser	
<i>Silene cucubaris</i>	0.50	Invader	
<i>Sisyrinchium montanum</i>	0.10	Increaser	
<i>Solidago spathulata</i>	7.03	Increaser	
<i>Taraxacum officinale</i>	2.12	Invader	
<i>Viola adunca</i>	3.09	Increaser	
Total Forbs	71.57		14.44
<i>Rosa woodsii</i>	0.69	Increaser	
<i>Symphoricarpos albus</i>	1.13	Increaser	
Total Shrubs	1.82		0.00
% Range Condition:			33.50
Total Vegetation	36.88		
Bare Soil	41.80		
Moss, lichen	23.31		
Litter	1.81		

Table 47B - Windy Point: Fenced % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	8.67	9.87	28	87.50	81.12	18.28
<i>Bromus pumpellianus</i>	2.42	3.67	25	78.13	21.41	4.82
<i>Calamagrostis montanensis</i>	0.58	6.98	4	12.50	2.04	0.46
<i>Carex filifolia</i>	3.77	5.99	24	75.00	32.61	7.35
<i>Carex scirpoidea</i>	0.64	6.65	4	12.50	2.26	0.51
<i>Carex pensylvanica</i>	1.63	4.87	14	43.75	10.75	2.42
<i>Koeleria macrantha</i>	2.22	3.96	20	62.50	17.54	3.95
Total Graminoids	19.92	14.30				37.80
<i>Arabis holoboelli</i>	0.23	0.98	7	21.88	1.10	0.25
<i>Arabis sp.</i>	0.30	0.81	11	34.38	1.74	0.39
<i>Artemisia campestris</i>	0.72	1.03	14	43.75	4.75	1.07
<i>Artemisia frigida</i>	13.94	12.92	31	96.88	137.18	30.91
<i>Comandra umbellata</i>	2.52	3.56	27	84.38	23.11	5.21
<i>Erigeron caespitosa</i>	0.42	0.98	7	21.88	1.97	0.44
<i>Erysimum inconspicuum</i>	0.09	1.41	2	6.25	0.23	0.05
<i>Galium boreale</i>	5.63	6.16	17	53.13	41.00	9.24
<i>Hedysarum boreale</i>	1.02	7.22	3	9.38	3.11	0.70
<i>Linum lewesii</i>	1.31	0.99	21	65.63	10.63	2.40
<i>Lithospermum incisum</i>	4.11	4.87	30	93.75	39.79	8.97
<i>Senecio streptanthifolius</i>	0.45	1.05	9	28.13	2.40	0.54
<i>Solidago spathulata</i>	1.17	0.90	19	59.38	9.03	2.03
Total Fabaceae Forbs	1.02	3.69				0.70
Total Forbs	31.91	16.29				62.20
<i>Nostoc spp.</i>	1.64	1.07				
Avg. No. Species	9.97	1.71				
Total Vegetation	51.83	24.14				
Bare Soil	8.30	10.06				
Moss, lichen	19.43	6.58				

Table 48B - Windy Point: Grazed % Canopy Cover (2002).

	Avg Cover	St. Dev.	Plots w sp	% Comp	Prom Value	% Prom Value
<i>Agropyron dasystachyum</i>	2.47	2.44	29	90.63	23.50	9.52
<i>Bromus pumpellianus</i>	0.16	0.82	6	18.75	0.68	0.27
<i>Calamagrostis montanensis</i>	0.36	1.07	7	21.88	1.68	0.68
<i>Carex filifolia</i>	7.44	8.68	22	68.75	61.67	24.98
<i>Carex scirpoidea</i>	1.73	6.71	8	25.00	8.67	3.51
<i>Carex pensylvanica</i>	0.25	1.00	4	12.50	0.88	0.36
<i>Koeleria macrantha</i>	1.36	0.94	23	71.88	11.52	4.67
Total Graminoids	13.77	10.07				44.00
<i>Antennaria parvifolia</i>	0.55	8.84	2	6.25	1.37	0.55
<i>Arabis holoboelli</i>	0.13	1.00	4	12.50	0.44	0.18
<i>Arabis sp.</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Artemisia campestris</i>	0.28	1.10	6	18.75	1.22	0.49
<i>Artemisia frigida</i>	8.84	8.24	25	78.13	78.17	31.67
<i>Erigeron caespitosa</i>	0.27	0.88	9	28.13	1.41	0.57
<i>Galium boreale</i>	1.67	3.07	18	56.25	12.54	5.08
<i>Linum lewesii</i>	1.05	0.99	13	40.63	6.67	2.70
<i>Lithospermum incisum</i>	3.72	4.44	30	93.75	36.01	14.59
<i>Potentilla pensylvanica</i>	0.08	0.00	1	3.13	0.14	0.06
<i>Senescio streptanthifolius</i>	0.02	0.00	1	3.13	0.03	0.01
<i>Solidago spathulata</i>	0.09	1.41	2	6.25	0.23	0.09
Total Forbs	16.70	9.91				56.00
<i>Juniperus horizontalis</i>	5.39	12.03	7	21.88	25.21	10.21
<i>Potentilla fruticosa</i>	0.47	0.00	1	3.13	0.83	0.34
Total Shrubs	5.86	11.70				10.55
<i>Nostoc spp.</i>	0.50	0.00				
Avg. No. Species	7.03	1.18				
Total Vegetation	36.33	17.06				
Bare Soil	58.52	11.00				
Moss, lichen	1.83	1.15				

Table 49B - Windy Point: Fenced % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron dasystachyum</i>	8.67	13.33	18.28	17.28
<i>Bromus pumpellianus</i>	2.42	4.33	4.82	4.23
<i>Calamagrostis montanensis</i>	0.58	0.67	0.46	0.27
<i>Carex filifolia</i>	3.77	13.02	7.35	14.45
<i>Carex scirpoidea</i>	0.64	0.50	0.51	0.12
<i>Carex pensylvanica</i>	1.63	5.08	2.42	4.17
<i>Koeleria macrantha</i>	2.22	9.25	3.95	11.16
Total Graminoids	19.92	46.18	37.80	51.68
<i>Antennaria parvifolia</i>	0.00	0.02	0.00	0.01
<i>Arabis holoboelli</i>	0.23	0.00	0.25	0.00
<i>Arabis sp.</i>	0.30	0.25	0.39	0.10
<i>Artemisia campestris</i>	0.72	2.10	1.07	1.99
<i>Artemisia frigida</i>	13.94	14.00	30.91	18.15
<i>Comandra umbellata</i>	2.52	2.08	5.21	1.56
<i>Erigeron caespitosus</i>	0.42	5.58	0.44	6.20
<i>Erysimum inconspicuum</i>	0.09	0.08	0.05	0.02
<i>Galium boreale</i>	5.63	2.92	9.24	2.18
<i>Hedysarum boreale</i>	1.02	0.50	0.70	0.12
<i>Linum lewesii</i>	1.31	6.92	2.40	6.94
<i>Lithospermum incisum</i>	4.11	8.50	8.97	9.43
<i>Senescio streptanthifolius</i>	0.45	0.25	0.54	0.10
<i>Solidago spathulata</i>	1.17	2.25	2.03	1.41
Total Fabaceae Forbs	1.02	0.50	0.70	0.12
Total Forbs	31.91	45.45	62.20	48.21
<i>Potentilla fruticosa</i>	0.00	0.50	0.00	0.12
Total Shrubs	0.00	0.50	0.00	0.12
<i>Nostoc spp.</i>	1.64			
Total Vegetation	51.83	92.13		
Bare Soil	8.30	47.75		
Moss, lichen	19.43	0.50		

Table 50B - Windy Point: Fenced % Canopy Cover (1995-2002).

	2002	1995	2002	1995
	Avg Cover	Avg Cover	% Prom	% Prom
<i>Agropyron dasystachyum</i>	2.47	12.92	9.52	20.03
<i>Bromus pumpellianis</i>	0.16	1.50	0.27	1.20
<i>Calamagrostis montanensis</i>	0.36	0.50	0.68	0.35
<i>Carex filifolia</i>	7.44	9.08	24.98	10.60
<i>Carex scirpoidea</i>	1.73	9.75	3.51	9.15
<i>Carex pensylvanica</i>	0.25	1.92	0.36	1.53
<i>Koeleria macrantha</i>	1.36	7.85	4.67	11.11
Total Graminoids	13.77	43.52	44.00	53.97
<i>Antennaria parvifolia</i>	0.55	0.00	0.55	0.00
<i>Arabis holoboelli</i>	0.13	0.00	0.18	0.00
<i>Arabis</i> sp.	0.02	0.08	0.01	0.02
<i>Artemisia campestris</i>	0.28	0.42	0.49	0.26
<i>Artemisia frigida</i>	8.84	9.25	31.67	13.35
<i>Comandra umbellata</i>	0.00	0.92	0.00	0.64
<i>Erigeron caespitosa</i>	0.27	8.17	0.57	11.32
<i>Erysimum inconspicuum</i>	0.00	0.25	0.00	0.12
<i>Galium boreale</i>	1.67	3.50	5.08	4.08
<i>Linum lewesii</i>	1.05	4.75	2.70	5.54
<i>Lithospermum incisum</i>	3.72	4.75	14.59	6.31
<i>Oxytropis splendens</i>	0.00	0.02	0.00	0.01
<i>Potentilla pensylvanica</i>	0.08	0.00	0.06	0.00
<i>Senescio streptanthifolius</i>	0.02	0.10	0.01	0.04
<i>Solidago spathulata</i>	0.09	1.58	0.09	0.90
Total Forbs	16.70	33.87	56.00	42.61
<i>Juniperus horizontalis</i>	5.39	4.92	10.21	3.41
<i>Potentilla fruticosa</i>	0.47	0.00	0.34	0.00
Total Shrubs	5.86	4.92	10.55	3.41
<i>Nostoc</i> spp.	0.50			
Total Vegetation	40.78	82.31		
Bare Soil	58.52	67.42		
Moss, lichen	1.83	1.25		

Table 51B - Windy Point: Fenced % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	12.31	Decreaser	12.31
<i>Bromus pumpellianus</i>	6.87	Decreaser	6.87
<i>Calamagrostis montanensis</i>	0.76	Decreaser	0.76
<i>Carex filifolia</i>	8.04	Decreaser	8.04
<i>Carex scirpoidea</i>	3.76	Decreaser	3.76
<i>Carex pensylvanica</i>	1.48	Decreaser	1.48
<i>Koeleria macrantha</i>	5.72	Increaser	5.72
Total Graminoids	38.95		38.94
<i>Arabis holoboelli</i>	0.57	Increaser	
<i>Arabis sp.</i>	1.09	Increaser	
<i>Artemisia campestris</i>	2.47	Increaser	
<i>Artemisia frigida</i>	18.57	Increaser	5.00
<i>Comandra umbellata</i>	7.04	Increaser	
<i>Erigeron caespitosus</i>	1.30	Increaser	
<i>Erysimum inconspicuum</i>	3.08	Increaser	
<i>Galium boreale</i>	8.78	Increaser	
<i>Hedysarum boreale</i>	1.81	Decreaser	1.81
<i>Linum lewesii</i>	5.03	Increaser	
<i>Lithospermum incisum</i>	8.71	Increaser	
<i>Senescio streptanthifolius</i>	1.23	Increaser	
<i>Solidago spathulata</i>	4.46	Increaser	
Total Forbs	64.13		6.81
		% Range Condition:	45.75
Total Vegetation	81.33		
Bare Soil	8.28		
Moss, lichen	8.25		
Litter	38.59		

Table 52B - Windy Point: Grazed % Biomass Method (2002).

	Avg % Comp	Grazing Response	Allowable% Composition
<i>Agropyron dasystachyum</i>	7.47	Decreaser	7.47
<i>Bromus pumpellianus</i>	0.45	Decreaser	0.45
<i>Calamagrostis montanensis</i>	1.04	Decreaser	1.04
<i>Carex filifolia</i>	18.46	Decreaser	18.46
<i>Carex pensylvanica</i>	0.72	Decreaser	0.72
<i>Carex scirpoidea</i>	3.97	Decreaser	3.97
<i>Koeleria macrantha</i>	4.72	Increaser	4.72
Total Graminoids	36.83		36.83
<i>Antennaria parvifolia</i>	2.39	Increaser	
<i>Arabis holoboelli</i>	0.52	Increaser	
<i>Arabis sp.</i>	0.15	Increaser	
<i>Artemisia campestris</i>	1.18	Increaser	
<i>Artemisia frigida</i>	27.47	Increaser	5.00
<i>Erigeron caespitosa</i>	1.01	Increaser	
<i>Galium boreale</i>	4.81	Increaser	
<i>Linum lewesii</i>	4.19	Increaser	
<i>Lithospermum incisum</i>	9.99	Increaser	
<i>Potentilla pensylvanica</i>	0.24	Increaser	
<i>Senescio streptanthifolius</i>	0.26	Increaser	
<i>Solidago spathulata</i>	0.22	Increaser	
Total Forbs	52.45		5.00
<i>Juniperus horizontalis</i>	9.39	Increaser	
<i>Potentilla fruticosa</i>	1.20	Increaser	
Total Shrubs	10.59		0.00
% Range Condition:			41.83
Total Vegetation	40.78		
Bare Soil	58.59		
Moss, lichen	0.09		
Litter	6.19		

Appendix C. Additional Chapter 2 Data and Methods

Table 1C - Soil and Vegetation sampling dates at 9 grassland sites in Jasper National Park, Alberta.

Site	Vegetation Sampling	Spring Soil Moisture	Fall Soil Moisture
Cottonwood Slough	July 15-16	May-21	Sep-10
Edna	July 17-18	May-26	Sep-18
Henry House	July 19-20	May-22	Sep-15
Moberly	July 21-23	May-23	Sep-14
Warden's Office	July 24-26	May-23	Sep-16
Cottonwood Point	July 27-28	May-24	Sep-13
Devona Hill	July 28-29	May-25	Sep-11
Richardson	July 29-30	May-26	Sep-09
Windy Point	July 31-Aug 1	May-25	Sep-17

Table 2C - Summary of Climatic Data for Jasper (1943-2000).

Year	Mean Maximum Temp (C)	Mean Minimum Temp (C)	Total Rainfall (mm)	Total Snowfall (cm)	Total Precip. (mm)
1943	9.9	-3.3	176.5	72.5	249.0
1946	10.3	-3.1	225.0	109.4	334.4
1949	8.8	-4.8	277.6	154.5	431.9
1952	9.6	-3.2	323.5	50.7	374.3
1957	8.8	-4.0	246.1	137.4	383.4
1962	9.4	-2.8	245.0	118.3	361.1
1965	8.2	-3.6	334.9	191.2	488.6
1968	8.5	-3.0	267.8	144.0	380.6
1972	7.5	-4.6	307.6	243.4	489.3
1975	8.0	-3.9	285.5	141.6	389.8
1978	8.4	-2.8	430.4	65.0	479.0
1983	9.2	-2.1	258.6	82.0	324.0
1988	10.2	-1.6	286.2	113.4	363.7
1993	9.6	-2.8	389.8	83.2	447.6
1994	9.7	-2.4	321.2	126.0	397.2
1996	7.5	-6.2	186.7	185.7	345.2
1997	10.0	-3.3	424.7	114.6	526.5
1998	11.2	-2.8	283.2	82.4	365.6
1999	10.6	-3.0	No Data	No Data	No Data
2000	9.4	-4.3	No Data	No Data	No Data

All Data from Environment Canada

1943-1994: Data from Jasper Weather Station

1996-2000: Data from Warden's Office Weather Station

Conversion of Relative % Frequency Data to % Canopy Cover

Methods

Because studies prior to 1995 expressed vegetation cover as relative % frequency (Cowan 1946, Banfield 1952, Trottier 1979), while I used % canopy cover, I needed to convert relative % frequency to % canopy to examine long-term trends in vegetation. I used my point intercept data from 2002, collected using a diagonal pin frame, to convert relative % frequency data from 1946 and 1952 to % canopy cover. I plotted the data using a simple linear regression to obtain the following equation (Fig. 1C):

$$\text{Canopy Cover} = 0.5856 (\text{relative \% frequency}) + 1.431 (r^2=0.71; P<0.001)$$

In 1995, Tannas (1997) double-sampled using point intercept, yielding relative % frequency, and % canopy cover methods at Devona flats, Moberly, Henry House, and Disaster Point. I compiled the data for all species present (i.e. cover >0%) at these 4 sites, using the relative % frequency (not mean) and average canopy cover from Tannas (1997; Table 4C and Fig.2C). I plotted the data using a simple linear regression to obtain the following equation:

$$\text{Canopy cover} = 1.1242(\text{relative \% frequency}) + 0.6135 (r^2=0.71, P<0.001);$$

I used these equations to convert all relative % frequency data prior to 1995 to % canopy cover.

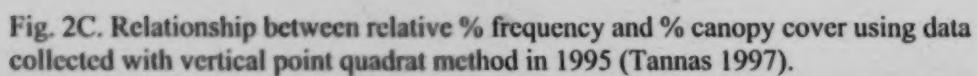
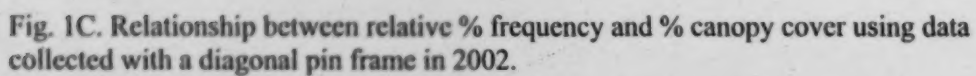


Table 3C. Data used from 2002 relative % frequency and % canopy cover to convert 1946 and 1952 relative % frequency to % canopy cover.

Species	Average % Canopy Cover	Relative % Frequency
<i>Achillea millefolium</i>	0.50	0.88
<i>Agropyron dasystachyum</i>	15.00	26.22
<i>Agropyron dasystachyum</i>	15.00	17.57
<i>Agropyron dasystachyum</i>	15.00	48.26
<i>Agropyron dasystachyum</i>	2.50	11.72
<i>Agropyron dasystachyum</i>	15.00	28.29
<i>Agropyron dasystachyum</i>	2.50	23.97
<i>Agropyron dasystachyum</i>	15.00	35.40
<i>Agropyron dasystachyum</i>	2.50	40.85
<i>Agropyron dasystachyum</i>	15.00	24.81
<i>Agropyron dasystachyum</i>	15.00	51.42
<i>Agropyron dasystachyum</i>	37.50	56.73
<i>Agropyron dasystachyum</i>	37.50	5.92
<i>Agropyron trachycaulum</i>	15.00	54.49
<i>Agropyron trachycaulum</i>	15.00	32.72
<i>Agropyron trachycaulum</i>	0.50	2.45
<i>Agropyron trachycaulum</i>	0.50	5.92
<i>Agropyron trachycaulum</i>	2.50	12.98
<i>Agropyron trachycaulum</i>	0.50	0.43
<i>Agropyron trachycaulum</i>	0.50	1.32
<i>Anemone multifida</i>	2.50	1.09
<i>Anemone multifida</i>	2.50	3.00
<i>Anemone multifida</i>	2.50	0.88
<i>Anemone patens</i>	0.00	0.86
<i>Anemone patens</i>	2.50	0.66
<i>Anemone patens</i>	2.50	1.21
<i>Anemone patens</i>	2.50	2.64
<i>Antennaria neglecta</i>	15.00	13.36
<i>Antennaria neglecta</i>	15.00	4.20
<i>Antennaria neglecta</i>	62.50	19.43
<i>Antennaria parvifolia</i>	62.50	28.68
<i>Antennaria parvifolia</i>	62.50	20.16
<i>Antennaria parvifolia</i>	15.00	12.45
<i>Antennaria parvifolia</i>	0.00	0.44
<i>Antennaria parvifolia</i>	0.00	0.22
<i>Arabis holoboelli</i>	0.50	0.00
<i>Artemisia campestris</i>	0.50	1.23
<i>Artemisia campestris</i>	15.00	10.74
<i>Artemisia campestris</i>	0.50	0.69
<i>Artemisia campestris</i>	0.50	2.11
<i>Artemisia campestris</i>	2.50	2.05
<i>Artemisia frigida</i>	0.50	4.73
<i>Artemisia frigida</i>	15.00	10.95
<i>Artemisia frigida</i>	0.50	0.00
<i>Artemisia frigida</i>	15.00	6.58

Species	Average % Canopy Cover	Relative % Frequency
<i>Artemisia frigida</i>	15.00	2.45
<i>Artemisia frigida</i>	37.50	39.35
<i>Artemisia tilesii</i>	0.50	1.65
<i>Artemisia tilesii</i>	0.50	2.11
<i>Artemisia tilesii</i>	2.50	14.71
<i>Astragulus striatus</i>	15.00	9.78
<i>Astragulus striatus</i>	2.50	1.00
<i>Astragulus striatus</i>	15.00	45.80
<i>Astragulus striatus</i>	2.50	19.27
<i>Astragulus striatus</i>	2.50	3.43
<i>Bromus inermis</i>	2.50	10.74
<i>Bromus inermis</i>	2.50	10.19
<i>Bromus inermis</i>	15.00	56.84
<i>Calamagrostis montanensis</i>	15.00	62.88
<i>Calamagrostis montanensis</i>	2.50	24.74
<i>Calamagrostis montanensis</i>	2.50	0.70
<i>Calamagrostis montanensis</i>	15.00	16.86
<i>Calamagrostis montanensis</i>	2.50	13.69
<i>Campanula rotundifolia</i>	2.50	1.32
<i>Campanula rotundifolia</i>	2.50	1.84
<i>Campanula rotundifolia</i>	0.50	1.03
<i>Campanula rotundifolia</i>	2.50	3.65
<i>Campanula rotundifolia</i>	2.50	4.36
<i>Campanula rotundifolia</i>	0.50	0.70
<i>Carex aurea</i>	0.00	9.54
<i>Carex filifolia</i>	0.50	8.26
<i>Carex filifolia</i>	15.00	40.91
<i>Carex filifolia</i>	15.00	24.56
<i>Carex pensylvanica</i>	0.50	3.95
<i>Carex stenophylla</i>	0.50	1.33
<i>Carex stenophylla</i>	0.50	1.55
<i>Cerastium arvense</i>	2.50	2.07
<i>Cerastium arvense</i>	2.50	12.88
<i>Comandra umbellata</i>	0.00	0.68
<i>Comandra umbellata</i>	2.50	6.21
<i>Comandra umbellata</i>	0.50	0.96
<i>Comandra umbellata</i>	0.50	1.41
<i>Comandra umbellata</i>	2.50	0.37
<i>Comandra umbellata</i>	2.50	3.00
<i>Comandra umbellata</i>	2.50	2.37
<i>Elymus innovatus</i>	15.00	31.76
<i>Erigeron caespitosus</i>	2.50	4.93
<i>Erigeron caespitosus</i>	2.50	5.21
<i>Erigeron caespitosus</i>	0.50	1.65
<i>Erigeron caespitosus</i>	0.50	1.24
<i>Erigeron caespitosus</i>	2.50	7.04
<i>Festuca saximontana</i>	0.50	1.21
<i>Festuca saximontana</i>	2.50	16.74

Species	Average % Canopy Cover	Relative % Frequency
<i>Festuca saximontana</i>	2.50	5.08
<i>Galium boreale</i>	2.50	2.48
<i>Galium boreale</i>	2.50	0.28
<i>Galium boreale</i>	0.50	0.23
<i>Galium boreale</i>	2.50	3.58
<i>Galium boreale</i>	2.50	10.63
<i>Galium boreale</i>	2.50	2.66
<i>Koeleria macrantha</i>	15.00	32.44
<i>Koeleria macrantha</i>	15.00	16.89
<i>Koeleria macrantha</i>	2.50	9.45
<i>Koeleria macrantha</i>	2.50	19.31
<i>Koeleria macrantha</i>	15.00	40.13
<i>Koeleria macrantha</i>	15.00	73.63
<i>Koeleria macrantha</i>	2.50	2.43
<i>Koeleria macrantha</i>	0.00	4.32
<i>Linum lewesii</i>	2.50	4.93
<i>Linum lewesii</i>	0.00	0.31
<i>Linum lewesii</i>	0.50	0.69
<i>Linum lewesii</i>	2.50	6.34
<i>Linum lewesii</i>	15.00	10.53
<i>Linum lewesii</i>	0.50	2.66
<i>Linum lewesii</i>	2.50	2.18
<i>Linum lewesii</i>	2.50	29.27
<i>Linum lewesii</i>	2.50	10.88
<i>Linum lewesii</i>	2.50	3.09
<i>Lithospermum incisuum</i>	2.50	2.66
<i>Poa compressa</i>	20.00	4.42
<i>Poa pratensis</i>	62.50	79.37
<i>Poa pratensis</i>	62.50	83.80
<i>Poa pratensis</i>	2.50	1.09
<i>Poa pratensis</i>	2.50	28.22
<i>Poa pratensis</i>	2.50	18.25
<i>Poa pratensis</i>	2.50	12.45
<i>Salsola kali</i>	15.00	4.61
<i>Salsola kali</i>	2.50	3.07
<i>Salsola kali</i>	2.50	2.82
<i>Senescio streptanthifolius</i>	2.50	1.93
<i>Sisyrinchium montanum</i>	2.50	1.74
<i>Solidago spathulata</i>	2.50	7.71
<i>Solidago spathulata</i>	2.50	0.70
<i>Solidago spathulata</i>	2.50	4.52
<i>Solidago spathulata</i>	2.50	0.35
<i>Solidago spathulata</i>	15.00	7.06
<i>Stipa richardsonii</i>	2.50	20.22
<i>Stipa richardsonii</i>	37.50	55.59
<i>Symphoricarpos albus</i>	15.00	3.09
<i>Vicia americana</i>	2.50	1.66
<i>Vicia americana</i>	15.00	5.57

Species	Average % Canopy Cover	Relative % Frequency
<i>Viola adunca</i>	2.50	3.83
<i>Viola adunca</i>	2.50	1.66
<i>Viola adunca</i>	2.50	2.57
<i>Viola adunca</i>	2.50	0.27
<i>Viola adunca</i>	0.50	0.22

Table 4C - Data values from Tannas (1997), from Henry House, Moberly, Devona flats, and Disaster Point, used in regression equation to convert % relative frequency to % canopy cover.

Species	Average % Canopy Cover	Relative % Frequency
<i>Agropyron dasystachyum</i>	18.92	13.19
<i>Agropyron dasystachyum</i>	3.67	1.73
<i>Agropyron dasystachyum</i>	2.08	1.19
<i>Agropyron trachycaulum</i>	1.14	0.13
<i>Agropyron trachycaulum</i>	0.67	0.24
<i>Anemone multifida</i>	1.58	2.82
<i>Anemone multifida</i>	0.44	0.08
<i>Antennaria parvifolia</i>	19.00	10.64
<i>Antennaria parvifolia</i>	8.08	3.12
<i>Artemisia campestris</i>	3.42	0.99
<i>Artemisia campestris</i>	2.00	1.92
<i>Artemisia frigida</i>	6.33	4.71
<i>Artemisia frigida</i>	5.42	0.72
<i>Artemisia frigida</i>	4.92	1.26
<i>Astragulus striatus</i>	9.58	10.10
<i>Astragulus striatus</i>	8.25	5.52
<i>Astragulus striatus</i>	7.17	9.93
<i>Astragulus striatus</i>	0.27	0.25
<i>Bromus pumpellianus</i>	4.56	1.85
<i>Bromus pumpellianus</i>	1.75	0.47
<i>Bromus pumpellianus</i>	0.63	0.63
<i>Calamagrostis montanensis</i>	8.00	8.70
<i>Calamagrostis montanensis</i>	5.50	5.81
<i>Calamagrostis montanensis</i>	5.00	5.69
<i>Calamagrostis montanensis</i>	3.50	8.44
<i>Calamagrostis purpurescens</i>	0.39	0.66
<i>Calamagrostis purpurescens</i>	0.08	0.55
<i>Campanula rotundifolia</i>	2.75	1.98
<i>Campanula rotundifolia</i>	1.83	0.74
<i>Campanula rotundifolia</i>	0.88	0.63
<i>Campanula rotundifolia</i>	0.42	2.12
<i>Campanula rotundifolia</i>	0.25	0.50
<i>Carex eburnia</i>	1.38	0.78
<i>Carex eburnia</i>	0.38	0.92
<i>Carex richardsonii</i>	1.44	0.16
<i>Carex richardsonii</i>	0.63	3.70
<i>Carex scirpoidea</i>	0.50	0.55
<i>Carex stenophylla</i>	3.08	2.02
<i>Carex stenophylla</i>	1.43	1.73
<i>Carex stenophylla</i>	0.67	1.74
<i>Carex stenophylla</i>	0.25	1.98

Species	Average % Canopy Cover	Relative % Frequency
<i>Carex stenophylla</i>	0.17	1.65
<i>Comandra umbellata</i>	1.76	0.55
<i>Comandra umbellata</i>	1.08	0.26
<i>Comandra umbellata</i>	1.00	0.24
<i>Eleagnus comutata</i>	0.58	0.25
<i>Elymus innovatus</i>	14.81	6.72
<i>Elymus innovatus</i>	7.92	10.35
<i>Elymus innovatus</i>	2.06	2.77
<i>Erigeron caespitosus</i>	5.75	3.84
<i>Erigeron caespitosus</i>	1.75	0.25
<i>Erigeron caespitosus</i>	0.08	2.12
<i>Fragaria virginiana</i>	1.19	0.66
<i>Fragaria virginiana</i>	0.25	0.08
<i>Galium boreale</i>	15.33	11.29
<i>Galium boreale</i>	10.75	9.38
<i>Galium boreale</i>	0.88	1.32
<i>Galium boreale</i>	0.00	0.25
<i>Koeleria macrantha</i>	13.83	11.51
<i>Koeleria macrantha</i>	9.08	7.18
<i>Koeleria macrantha</i>	6.42	2.12
<i>Koeleria macrantha</i>	3.50	5.20
<i>Koeleria macrantha</i>	1.55	3.04
<i>Koeleria macrantha</i>	1.50	0.99
<i>Koeleria macrantha</i>	1.26	0.63
<i>Linum lewesii</i>	9.83	3.72
<i>Linum lewesii</i>	4.33	1.52
<i>Linum lewesii</i>	3.75	1.65
<i>Linum lewesii</i>	1.42	0.74
<i>Linum lewesii</i>	0.83	0.26
<i>Linum lewesii</i>	0.58	1.44
<i>Oxytropis splendens</i>	1.08	0.74
<i>Poa compressa</i>	0.08	0.00
<i>Poa pratensis</i>	3.50	6.59
<i>Poa pratensis</i>	1.75	0.00
<i>Senescio streptanthifolius</i>	1.50	0.48
<i>Senescio streptanthifolius</i>	0.92	1.24
<i>Sisyrinchium montanum</i>	2.42	0.25
<i>Solidago spathulata</i>	5.06	3.83
<i>Solidago spathulata</i>	3.67	0.74
<i>Solidago spathulata</i>	3.38	1.33
<i>Solidago spathulata</i>	2.50	0.24
<i>Solidago spathulata</i>	1.67	0.48
<i>Solidago spathulata</i>	1.50	0.25
<i>Symphoricarpos occidentalis</i>	9.92	6.57
<i>Taraxacum officinale</i>	13.92	8.15

Species	Average % Canopy Cover	Relative % Frequency
<i>Taraxacum officinale</i>	1.92	0.47
<i>Vicia americana</i>	0.83	0.24
<i>Viola adunca</i>	12.92	8.71
<i>Viola adunca</i>	1.56	1.19
<i>Zigadenus elegans</i>	0.38	0.16

Table 5C. Comparison of Banff and Jasper Climate.

JNP Weather Data	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Daily Max Temp (C)	-6	-0.3	4.2	10.1	15.4	19.5	22.2	21.7	16.2	10.3	0.5	-5.5	9
Daily Min Temp (C)	-15.6	-5.9	-1.6	3.8	8.8	12.8	15.1	14.6	9.8	4.7	-4	-9.7	-2.8
Rainfall (mm)	4.6	2.7	4.2	12.1	27.8	49.6	56.2	50.5	36	24.1	9.2	4.4	281.6
Snowfall (cm)	34.7	19.3	14.7	10.4	0.9	0.3	0	0.1	1	7.7	24.7	36.2	143.9
Precipitation (mm)	31.1	17.4	15.7	21.2	28.6	49.9	56.2	50.6	37	30.9	28.2	26.8	393.7
Relative Humidity	81	81	81	80	80	81	83	87	87	82	84	82	

BNP Weather Data	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Daily Max Temp (C)	-5.3	0.1	3.8	9	14.2	18.7	22.1	21.6	16.1	10.1	0.5	-5.3	8.8
Daily Min Temp (C)	-14.9	-11.3	-7.9	-2.8	1.5	5.4	7.4	6.8	2.7	-1.1	-8.2	-13.8	-3
Rainfall (mm)	2.4	1.7	1.6	10.5	42.4	58.4	51.1	51.2	37.7	15.4	6	2.8	281.2
Snowfall (cm)	38.2	30	27	26.3	17.1	1.7	0	0	7	18.9	33.6	43.9	243.8
Precipitation (mm)	31	23.9	21.5	32.4	57.5	60	51.2	51.3	43.8	30.3	30.4	34.6	468
Relative Humidity	78	78	76	77	79	78	80	83	82	77	78	79	

Appendix D: Additional Chapter 3 Data and Methods

Table 1D- Schedule for clipping and soil sampling, 2001.

Site	Winter Clipping	Spring Clipping	1st Summer Clipping	2nd Summer Clipping	Spring Initial Soil Sampling	Spring Final Soil Sampling	Fall Initial Soil Sampling	Fall Final Soil Sampling
Cottonwood Point	Feb-17	May-25	Jun-22	Jul-26	May-25	Jun-22	Sep-04	Oct-03
Cottonwood Slough	Feb-21/Apr-26	May-28	Jun-25	Jul-21	May-28	Jun-25	Sep-05	Oct-09
Devona Hill	Feb-20	May-26	Jun-23	Jul-25	May-26	Jun-23	Sep-03	Oct-04
Edna	N/A	N/A	N/A	N/A	N/A	N/A	Sep-04	Oct-02
Henry House	Feb-18	May-28	Jun-25	Jul-27	May-28	Jun-25	Sep-05	Oct-07/08
Moberly	Feb-22	May-23	Jun-20	Jul-20	May-23	Jun-20	Sep-01	Sep-29
Richardson	Feb-23	May-27	Jun-24	Jul-22	May-27	Jun-24	Sep-02	Sep-30
Warden's Office	Feb-23/Apr-26	May-24	Jun-21	Jul-28	May-24	Jun-21	Sep-02	Oct-01
Windy Point	Feb-19	May-26	Jun-23	Jul-25	May-26	Jun-23	Sep-03	Oct-06

Table 2D- Schedule for clipping and soil sampling, 2002.

Site	Winter Clipping	Spring Clipping	1st Summer Clipping	2nd Summer Clipping	Spring Initial Soil Sampling	Spring Final Soil Sampling	Fall Initial Soil Sampling	Fall Final Soil Sampling
Cottonwood Point	Jan-09	May-16	Jun-22	Aug-19	May-24	Jun-22	Sep-13	Oct-11
Cottonwood Slough	Jan-11/Apr-28	May-14	Jun-19	Aug-18	May-21	Jun-19	Sep-12	Oct-09
Devona Hill	Jan-08	May-19	Jun-25	Aug-20	May-25	Jun-25	Sep-11	Oct-10
Edna	N/A	N/A	N/A	N/A	May-26	Jun-23	Sep-18	Oct-17
Henry House	Jan-07	May-17	Jun-21	Aug-23	May-22	Jun-21	Sep-15	Oct-14
Moberly	Jan-10	May-15	Jun-20	Aug-24	May-22/23	Jun-20	Sep-14	Oct-12
Richardson	Jan-10	May-20	Jun-24	Aug-22	May-26	Jun-24	Sep-10	Oct-08
Warden's Office	Jan-09	May-18	Jun-23	Aug-21	May-23	Jun-23	Sep-16	Oct-15
Windy Point	Jan-08	May-19	Jun-25	Aug-20	May-25	Jun-25	Sep-17	Oct-16

Table 3D. Root biomass (g m^{-2}), N mineralization ($\mu\text{g N g}^{-1} \text{ day}^{-1}$) and microbial biomass C ($\mu\text{g C g}^{-1}$) at exclosures established in 1956 ($n=2$) and 1995 ($n=5$).

	1956 Control	1956 Grazed	1995 Control	1995 Grazed
Root Biomass				
Mean	132.6	192.2	114.9	107.3
s.d.	115.0	165.1	103.0	53.4
N mineralization				
Mean	0.074	0.208	0.111	0.139
s.d.	0.181	0.264	0.213	0.262
Microbial Biomass				
Mean	1002.9	1069.5	842.0	749.9
s.d.	321.1	362.1	217.8	254.1